MANUFACTURE OF CEMENT

Manufacture of Cement

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MANUFACTURE OF CEMENT
Parts 1–2

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NOTE.—This book is made up of separate parts, or sections, as indicated by their titles, and the page numbers of each usually begin with 1. In this list of contents the titles of the parts are given in the order in which they appear in the book, and under each title is a full synopsis of the subjects treated.

MANUFACTURE OF CEMENT, PART 1

MANUFACTURE OF CEMENT, PART 2

MANUFACTURE OF CEMENT

(PART 1)

MORTAR MATERIALS

GENERAL CLASSIFICATION

1. Relation Between Portland Cement and Other Mortar Materials.—Mortar materials may be classified according to their properties, methods of manufacture, and materials from which they are made, as follows:

1. *Common limes* are made by burning relatively pure limestone. When mixed with water they slake and show no hydraulic properties.

2. *Hydraulic limes* are made by burning impure limestone at low temperatures. They slake with water, but show hydraulic properties.

3. *Natural cements* are made by burning impure limestones at a low temperature (insufficient to vitrify). They do not slake with water but require to be ground in order to convert them into a hydraulic cement.

4. *Portland cement* is made by heating to incipient vitrification an intimate mixture of an argillaceous substance such as clay or shale, and calcareous substances, such as limestone or marl, in which mixture the percentage of silica, alumina, and iron oxide bear to the percentage of lime the ratio of approximately 1 : 2, which vitrified product does not slake with water but upon grinding forms an energetic hydraulic cement.

5. *Puzzolan cements* are made by incorporating slaked lime with finely-ground slag or volcanic ash or by incorporating a

small proportion of Portland cement clinker with suitably treated slag and grinding the mixture intimately.

6. *Plasters* are made by heating gypsum sufficiently to drive off three-fourths or all of the combined water which it contains and grinding finely the more or less dehydrated residue.

TABLE I
MATERIALS, TREATMENT, AND PROPERTIES OF LIMES AND CEMENTS

Classification	Raw Materials	Heat Treatment	Mechanical Treatment	Properties
1. Common limes......	Made from relatively pure limestones	Burned at low temperatures —600–900° C.	Slake on addition of water to burned product	Not hydraulic
2. Hydraulic limes......	Made from argillaceous or impure limestone	Burned at low temperatures —600–900° C.	Slake on addition of water to burned product	Hydraulic
3. Natural, Roman, or Rosendale cement	Made from argillaceous or impure limestone	Burned at low temperatures —600–900° C.	Do not slake on addition of water, but must be ground fine	Hydraulic
4. Portland cement....	Made from an intimate mixture of argillaceous and calcareous substances in proper proportions	Burned at high temperatures —600 – 1,200° C.	Do not slake on addition of water, but must be ground fine	Hydraulic
5. Slag or puzzolan cements	Made from mixtures of slaked lime and blast-furnace slag or volcanic ash	Not burned	Do not slake on addition of water, but must be ground fine	Hydraulic
6. Plasters.....	Made from gypsum	Burned at from 165–200° C.	Do not slake on addition of water, but must be ground fine	Not hydraulic

The materials, treatment, and properties of the limes and cements mentioned in the preceding classification are given in Table I.

2. Historical Development.—The use of lime as a building material antedates written history. Both the Egyp-

tians and the Romans improved on lime, which hardens in air only, by mixing volcanic ash with it.   This produced a puzzolan cement which would harden under water, and the Romans used such cement in many of their engineering works such as the aqueduct which supplied Rome with water.   The pyramids were constructed with a mortar made from plaster of Paris. John Smeaton, the engineer who built the Eddystone light-house, discovered hydraulic lime while searching for some hydraulic cement which he could use in the lighthouse.   Roman cement was probably first made by Joseph Parker in 1796 in Kent County, England.

Joseph Aspdin, a bricklayer of Leeds, England, invented Portland cement in 1824 and secured a patent on the process. He called his material *Portland* cement because when it hardened it produced a yellowish-gray mass resembling stone from the famous quarries of Portland, England.

Rock suitable for the manufacture of natural cement was first discovered in America in 1819 by Canvass White in Madison County, New York. (The first successful American Portland cement plant was built by David O. Saylor at Siegfried, Northampton County, Pennsylvania, who employed the local argillaceous limestone for this purpose.

The manufacture of a puzzolan cement from blast-furnace slag and slaked lime was first carried out successfully in Germany and was begun in the United States in 1896 by the Illinois Steel Company.   Several other companies also engaged in manufacturing *slag cement*, as it is commonly called, in various parts of the United States.   None of these now manu-facture slag cement, however.

3.   Cement and Lime Industry.—The cement industry is one of the great basic industries of the country.   Natural cement was at one time extensively manufactured in America, but now only a few plants make this material, which is used for laying brick and tile; but for concrete, Portland cement has entirely displaced both natural and puzzolan cements. Hydraulic limes were never made to any extent in this country, natural cement taking their place.

Portland cement plants are now located in most of the states of the Union, as the raw materials are widely distributed. These plants have an annual capacity in excess of 100,000,000 barrels. Lime is made practically all over the United States, the annual production being about 3,350,000 tons of quicklime and 850,000 tons of hydrate. The manufacture of plaster is also an important industry, the production being 2,000,000 tons annually.

LIMES AND PLASTERS

COMMON LIMES

COMPOSITION AND MANIPULATION OF RAW MATERIALS

4. Varieties of Limestone.—*Limestone*, the raw material from which lime is manufactured, is one of the most widely distributed rocks and it is found in nearly all countries. It usually occurs in stratified beds of considerable extent showing evidences of having been deposited at a time when the country was under water. Limestone was formed during all geological epochs from the earliest to the present, and some such epochs, the Trenton for example, were distinctly limestone-forming periods. At a given time, however, limestone may have been forming at one point and sandstone or clay at another.

Limestone, according to its physical properties, is known under various other names. The term *marl* is usually applied to the loose, granular, non-coherent limestone which was deposited in comparatively recent times in existing or extinct lakes. This material is now extensively used in the manufacture of Portland cement. *Marble* is limestone that after its formation has been subjected to sufficient heat and pressure from geological disturbances to make it more or less crystalline. *Chalk* is a soft, fine-grained limestone composed of finely comminuted shells. *Oolitic limestone* resembles a mass of fish roe and is made up of small round grains. *Calcareous tufas* and

travertine are limestones deposited by carbonated spring or stream waters along their courses. *Stalagmites* and *stalactites* are the icicle-like forms of limestone usually found in caves, the former projecting upwards from the floor and the latter hanging downwards from the roof of the cave. They are formed by the drip from the roof of water holding carbonate of lime in solution.

5. Chemical Composition of and Impurities in Limestone.—Limestone consists technically of more or less pure calcium carbonate, $CaCO_3$. In its purest crystalline state it forms the mineral calcite or calc spar. Calcite contains 56 per cent. of lime and 44 per cent. of carbon dioxide. It is found crystallized in the rhombohedral form and when cracked usually breaks up into smaller crystals of the same form as the large ones. Calcite containing as much as 99.8 per cent. of calcium carbonate is sometimes found. Marbles, stalactites, etc., are also very pure and sometimes contain as much as 99 per cent. of calcium carbonate. Limestone itself seldom contains more than 98.5 per cent. of calcium carbonate. Limestones containing much magnesia are called *dolomitic limestones*. The mineral dolomite is a double carbonate of calcium and magnesia containing when pure 30 per cent. of lime, 22 per cent. of mganesia, and 48 per cent. of carbon dioxide.

The principal impurities in limestone are silica, iron, alumina, and sulphur. Silica occurs in the free state as sand or combined as silicate of alumina, while alumina occurs only in the form of the silicate. Iron may occur as carbonate, oxide, or sulphide, and magnesia is generally found as carbonate. Sulphur may occur as sulphide of iron or as sulphate of calcium or magnesia.

Calcium oxide and magnesium oxide are the essential elements in lime, the other components being considered impurities. The purer the lime the better it is, and hence the purer the limestone the better lime it will make. The blue and gray color usually associated with limestone is caused by the presence of organic matter. This organic matter burns when the

limestone is heated and hence the color of the limestone is not often any indication of the quality of lime it will produce. Some nearly black limestones burn to a white lime.

6. Burning of Limestone.—If limestone or calcium carbonate is heated to 800° C. or over, decomposition takes place and carbon dioxide, CO_2, is driven off and calcium oxide, CaO, or lime, remains. The reaction that takes place may be expressed as follows:

Limestone, $CaCO_3$, + heat = lime, CaO, + carbon dioxide, CO_2

As pure limestone contains 56 per cent. of lime, 100 pounds of limestone will produce 56 pounds of lime. Ordinarily limestone contains some mineral impurities, which are not volatile and hence remain in the lime when the limestone is burned, so that generally 100 pounds of limestone will produce more than 56 pounds of lime. In view of the fact that approximately 44 per cent. (all the carbon dioxide) of the lime is volatile, lime always contains a much higher percentage of impurities than the limestone from which it is produced.

To calculate the quality of lime which will be produced from any limestone, it is necessary only to divide the percentage of each constituent by 100 less the percentage of carbon dioxide (or loss on ignition) and multiply the quotient by 100. If a limestone contained 2 per cent. silica and 42 per cent. carbon dioxide, the resulting lime would contain $[2 \div (100-42)] \times 100 = 3.45$ per cent. silica.

The heat necessary to decompose calcium carbonate into carbon dioxide and lime is equivalent to 1,451 British thermal units per pound of lime produced.

7. Common Lime Kilns.—The process of burning limestone is carried out in lime kilns of various types. The primitive kind is still used by farmers for burning limestone for agricultural purposes. It is rudely constructed of stone and located on a hillside where the top is readily accessible for charging the kiln with limestone and the bottom for drawing out the lime. The kiln itself consists merely of a pot-shaped structure with stone walls and has a diameter of 8 or 10 feet at the top and a height of 15 or 20 feet. In burning, fuel is

charged on grate bars at the bottom and over this is piled a layer of limestone broken to a convenient size. Other layers of fuel and limestone are then put in until the kiln is full. Fire is then kindled and allowed to burn until all the fuel is consumed, which requires several days, and after the contents of the kiln are sufficiently cool to handle, the burned lime is drawn out. This process of burning is wasteful of fuel owing to the amount used to heat up the kiln for each burning; also, much time is lost in loading, heating, and cooling the charge.

8. Continuous Lime Kilns. To avoid these objectionable features there are now in use what are known as continuous kilns, in which the limestone and the fuel are charged into the kiln at the top and the burned lime is drawn out at the bottom, no cooling of the kiln being necessary. Fig. 1 shows a continuous kiln. It is lined with firebrick and often is from 25 to 30 feet high. Its greatest diameter is usually 8 or 10 feet and its diameter at the top and the bottom is from 4 to 6 feet.

FIG. 1

The kiln is provided with an arrangement whereby the lime may be drawn at regular intervals from below. This type of kiln is also built on the side of a hill, usually of limestone blocks, and is often lined with firebrick. In charging the kiln, first a layer of small size coke or anthracite coal and then a layer of limestone is fed into the top. Fire is started at the bottom and works its way up. The process of charging and drawing the lime is continuous. These kilns are economical of fuel and for the same-sized kiln yield a larger quantity of product than do the flame kilns described later. On the other hand, the lime is contaminated by the ash of the fuel and the lime burned in these kilns must be care-

FIG. 2

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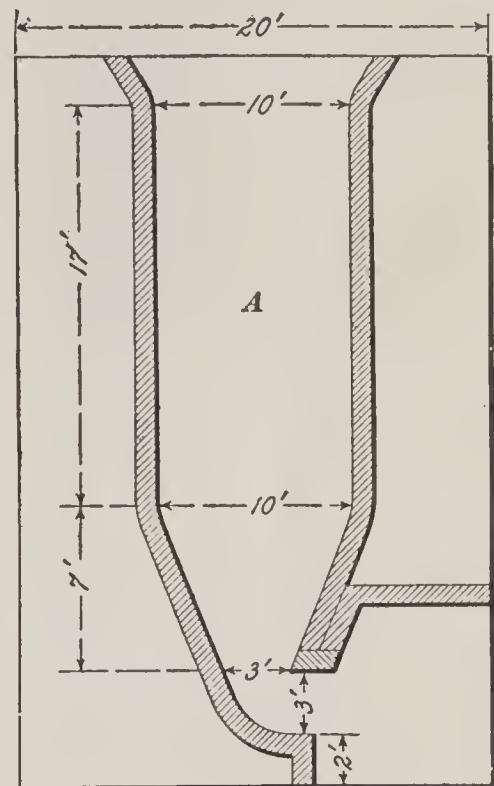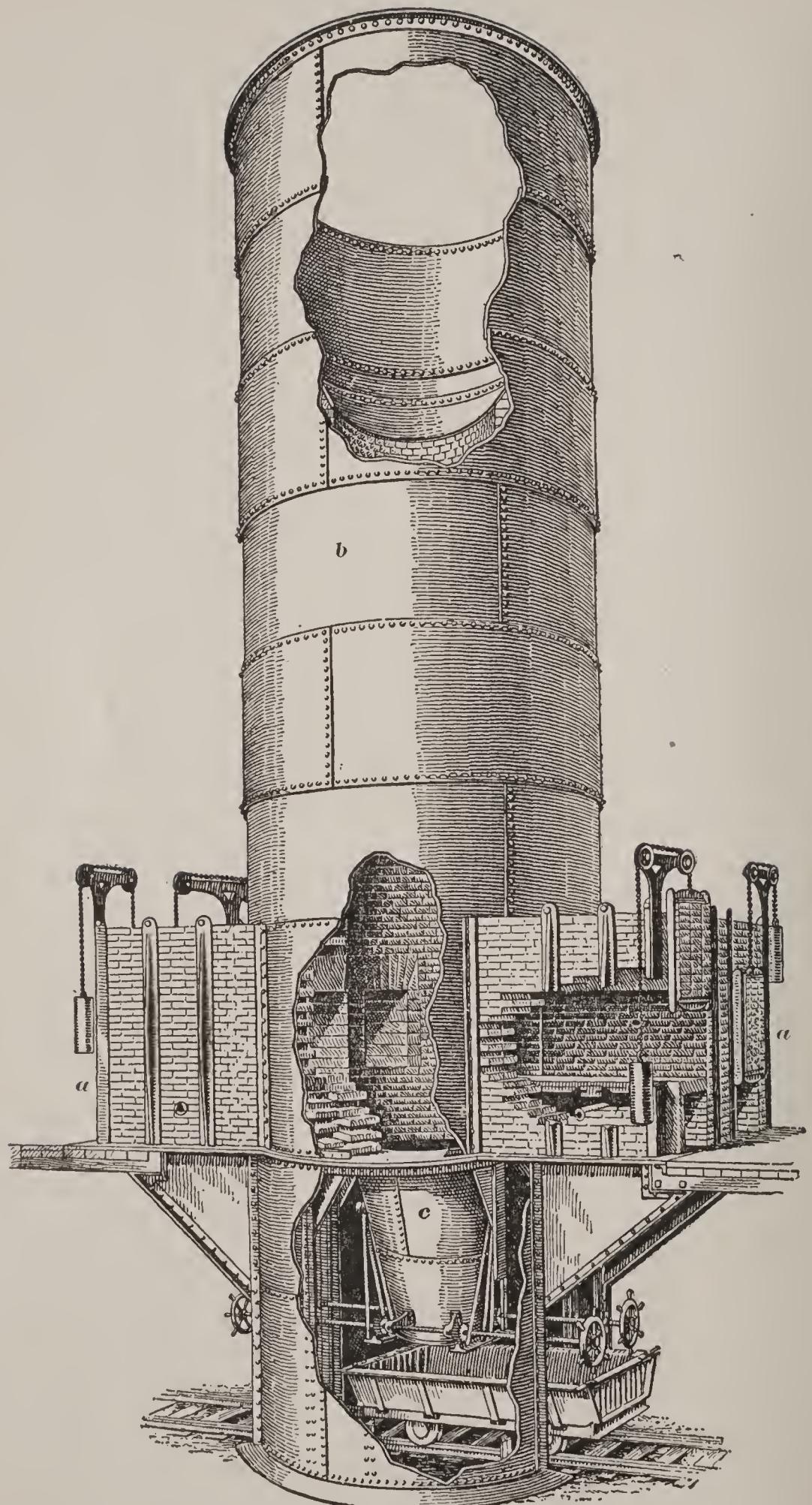
fully sorted in order to discard those lumps to which fuel ash has adhered. Many old lime plants are equipped with these kilns, but practically all plants aiming to make a high-grade building and chemical lime now use flame kilns. Kilns of this type are known as *mixed-feed* kilns because the fuel is mixed with the limestone. Mixed-feed kilns are also made similar to the flame kiln shown in Fig. 2, except that the fireboxes on each side of the shaft are omitted.

9. Flame Kilns.—When a white lime is required, flame kilns are used. As seen from the illustration, the fireplaces *a* are distinct from the body of the kiln. The limestone is charged into the main body *b,* the fuel in the fireplaces is kindled, and the hot gases rise up through the limestone into the kiln. The finished lime is withdrawn through *c.* Flame kilns are usually from 40 to 50 feet high and from 5 to 8 feet inside diameter, and equipped with either two or four furnaces. Kilns of this kind are now installed in all the larger lime-burning plants, as, taking everything into consideration, they not only give a more satisfactory product but are easier to control and hence more economical.

In a well-designed flame kiln, the shaft is divided into three parts. The upper section, or hopper, unlined with firebrick, forms a bin for the storage of stone, so that the kiln may be kept supplied at night when the quarry is not working. The middle section, or kiln proper, is lined with firebrick and in this the stone is burned, the last trace of carbon dioxide being driven off as it passes down past the *arch* or opening connecting the firebox and the shaft. The lower section, or cooling cone, is not lined with firebrick and is placed in such a way that air can pass around it freely and not only cool the lime but also prevent the cone itself from being burned out. The bottom of the cone is closed by means of a pair of swinging or sliding doors which allow the lime to drop into a barrow placed below the cone.

A kiln 6 feet in diameter by 50 feet high will produce about 10 tons of lime per day. Most lime plants therefore employ several such kilns. They are usually arranged in a row with

the fireboxes at right angles to the row, and charged from an incline and a cable hoist by means of which the cars of limestone are drawn from the quarry to the top of the kilns. The fireboxes rest on a floor usually of steel and concrete which extends from 10 to 15 feet beyond the end of the furnace, to provide room for the fireman to stoke his fires properly. The lime is drawn at intervals of 3 to 6 hours, although a few plants draw oftener and some less frequently. The objection to drawing too frequently is that each time the lime is drawn cold air enters the kiln through the drawing doors and cools the charge.

10. Fuel Required to Burn Lime.—Wood, coal, oil, natural and producer gas are employed for heating these kilns. Wood is the best fuel for burning lime, as wood burns with a long flame of comparatively low temperature. This is an advantage, as it is essential that the heating should be carried for a considerable distance inside the kiln, so as to burn the lime completely in the center, without having the temperature at the arch or the mouth of the firebox so high that it will fuse the lime just in front of it. Wood-burned lime is whiter than lime burned with coal. Kilns fired with wood also require less attention and skill in operating. Wood, however, is becoming scarce in nearly all lime-producing sections and hence it is rapidly ceasing to be a fuel for this purpose.

Where coal is employed this is usually *long flame* coal, high in volatile matter, and preferably low in sulphur and ash. It is the usual practice to wet the coal before charging into the furnace in order to supply steam and make the coal flame resemble more nearly that of wood. A steam jet is also often employed, it being inserted under the grate bars. The steam passing up through the bed of the hot coals is decomposed and forms hydrogen and carbon monoxide according to the reaction $H_2O + C = CO + H_2$. Both of these are combustible gases which, passing through the arches, burn in the kiln itself and hence carry the heating zone farther into the latter.

Oil is used for burning lime when it can be obtained more cheaply than coal and when atomized with steam it makes a

fuel almost as satisfactory as wood. It is used in kilns of the type shown in Fig. 2, by placing the oil jet in the door of the firebox, after covering the grate bars with firebrick or filling in to this point with some suitable material. The door of the firebox is partly bricked in with firebrick, leaving openings for the jet, for observing the lime, etc. Natural gas has been used for burning lime, but the high temperature of its flame is objectionable.

The quantity of fuel required to burn a ton of lime when properly used is about as follows: 1 ton of bituminous coal, hand fired, will burn 3 to 4 tons of lime; 1 cord of seasoned hardwood will burn 2 to $2\frac{1}{2}$ tons of lime; 1 barrel of fuel oil will burn $\frac{3}{4}$ to 1 ton of lime.

11. Producer Gas-Fired Kilns.—Lime kilns are now often heated with producer gas, particularly in large plants, as one of its principal advantages is the fact that very much larger gas-fired kilns can be built than is possible with hand firing on a grate. Some gas-fired kilns have a capacity of 40 to 50 tons of lime per day. This increased size of the kiln is made possible by the introduction of gas and air at various points around the kiln so as to obtain uniform temperatures throughout the stack. Even a kiln of the size described in Art. **10** will produce 20 to 25 tons of lime per day when heated with producer gas. Producer-gas kilns are slightly more economical of both fuel and labor than grate-fired kilns. Unless carefully handled, however, the lime obtained is burned very unevenly.

In Fig. 3 is shown a gas-fired kiln quite similar to the hand-fired kiln, the gas ports taking the place of the fireboxes of the latter. At d and d are the gas ports. The flow of gas is regulated by means of the valves e, which are counterbalanced by a weight. The gas mains leading from the producer are shown at f. The top of the kiln is closed by means of a hopper and bell g similar to that used with blast furnaces. Draft is secured by an exhauster (not shown), the gas being drawn off through the flue h. The producers, not shown in the drawing, should be located as near the kiln as possible and should be arranged so that they can be charged with coal and the ashes removed

with the minimum amount of labor. Producers for lime burning should give a gas of regular composition which need not, however, be of high thermal value. Quite a number of the
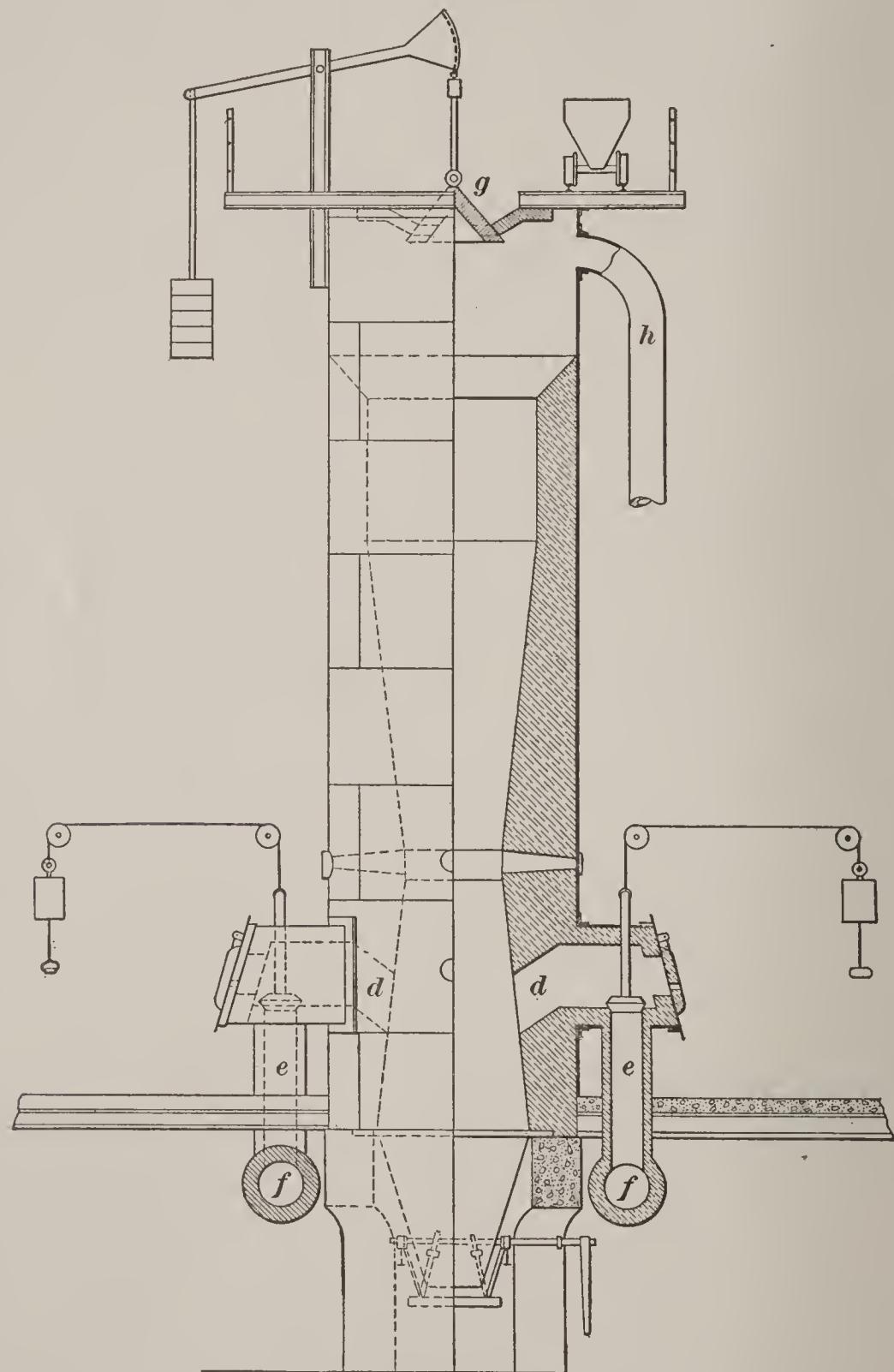
Fig. 3

standard gas producers have been employed with lime kilns, and where properly handled give good results. More skill is required in burning lime with producer gas than with any other

fuel. A well-designed gas-fired kiln will require about 1 ton of bituminous coal for every 5 to 6 tons of lime burned.

12.   Rotary Kilns for Lime.—The rotary kiln described later on is employed to some extent for lime burning, generally for lime which is to be used for agricultural, chemical, or metallurgical purposes, or for the manufacture of hydrate, as the fine lime produced is not popular in the building trades. For this purpose the kiln is heated by producer gas or pulverized coal and the limestone is crushed to a 2-inch size and under before being put into the kiln.

The advantages of the rotary kiln are its low labor cost of operating and the uniformity with which it burns, if properly handled. The labor item of lime burning can be cut in half by operating a rotary kiln. The greatest advantage of the rotary kiln, however, is the fact that small stone can be burned in it. For this reason, a rotary kiln is often used to burn up the limestone chips which are found in all quarries. The rotary kiln is also suited for burning stones which break up into smaller pieces and crumble on heating. Stone of this type can not be burned in upright kilns because of the stopping up of the draft by the spalls.

Certain waste products of manufacturing operations, as, for example, the precipitated carbonate of lime from beet-sugar manufacture and the lime waste from wood pulp made by the soda process, can be successfully burned in only the rotary kiln. A rotary kiln 8 feet in diameter by 125 feet long will produce daily about 100 tons of lime and will require about 1 ton of coal to produce 4 to $4\frac{1}{2}$ tons of lime.

A rotary kiln used for lime does not differ materially from a cement kiln except that producer gas is often used to heat the lime kiln. Rotary coolers are usually placed after the kiln to cool the lime and the stone is fed from a bin into the kiln in a regular stream.

13.   Characteristics of Lime.—The lime drawn from kilns consists of hard, rock-like, white or light-colored lumps, together with more or less fine powder. Lime is highly refractory and resists the highest heat of a furnace without

fusing. Freshly burned lime has a strong affinity for water and absorbs considerable moisture from air with a marked evolution of heat. This is due to the chemical union of lime with water in forming calcium hydrate,* $Ca(OH)_2$, or what is known as *slaked lime,* the reaction being as follows:

$$CaO + H_2O = Ca(OH)_2$$
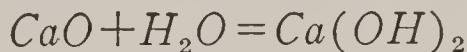
The slaking is accompanied by a considerable increase in volume as well as weight, since 56 parts of lime combine with 18 parts of water to form 74 parts of slaked lime, or calcium hydrate. Slaking may be accomplished either by exposure to moist air or by the addition of water. When mixed with sand for use as mortar, slaked lime hardens because of the absorption of carbon dioxide from the air and the consequent formation of calcium carbonate, which serves to bind together the grains of sand. The chemical reaction is as follows:

$$Ca(OH)_2 + CO_2 = CaCO_3 + H_2O$$
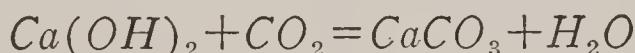
14. Slaking of Lime.—All lime, whether used in sand mortar for masonry or plaster or almost pure for finishing work in plastering, must be perfectly slaked before using. Very frequently too little attention is paid to slaking and defective work results. The reason is obvious. If lime is only partly slaked, it consists of a mixture of quicklime, CaO, and calcium hydrate, $Ca(OH)_2$, and when mixed with sand and put in work, even with excess of water, some quicklime may still remain. The water evaporates rapidly and the mass may become sound and hard, but it still contains quicklime having a strong affinity for moisture, which must be obtained from the atmosphere. The process of hydration may prevent hardening of mortar to a certain extent, but hardening advances as the amount of free lime grows less, and some of the lime must become hydrated after the first stage in hardening. As hydration is accompanied by a considerable increase in volume, the mass swells or expands and peels or cracks, making the work very defective. It is therefore recommended that lime be thoroughly slaked for at least a week before being

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*It should be remembered that the word *hydrate* is the commercial term for *hydroxide.*

used, but this practice is not always followed.   In some cases specifications require even a longer period.

15.   Magnesian Limestones.—Limestones frequently contain considerable magnesia.   When the magnesian limestones are burned, the resulting lime differs somewhat in properties from that burned from a purer limestone.   Magnesian limes slack much slower than do high-calcium limes and with evolution of much less heat, and there is no danger of burning, but time must be given it to hydrate thoroughly. Magnesian limes do not swell quite so much as the high-calcium lime when slaked, but shrink less when they harden.

Magnesian mortars generally work more smoothly and spread more freely under the trowel than high-calcium limes.

TABLE II
ANALYSES OF BUILDING LIMES

Ingredients	Percentage of Ingredients in Lime				
	1	2	3	4	5
Silica, SiO_2	.79	1.02	1.38	.61	.46
Iron oxide, Fe_2O_3, and alumina, Al_2O_3.	.26	.68	.62	.25	1.10
Lime, CaO	97.48	96.46	97.80	56.92	55.49
Magnesia, MgO	1.40	.64	.18	38.09	42.31
Carbon dioxide, CO_2, water, H_2O, etc.		1.20		2.75	.64

Hence, magnesian mortars are generally preferred by plasterers.   The high-calcium limes, on the other hand, give a larger volume of *putty* and carry more sand, so that when they can be used they are often cheapest.   Magnesian limes are generally considered stronger than high-calcium limes.

16.   Composition of Limes.—In Table II are given some analyses of lime from various parts of the United States. Column 1 gives the composition of lime from Chazy, New

York; column 2 that of lime from Glens Falls, New York; column 3 that of lime from Bedford, Indiana; while columns 4 and 5 give the composition of magnesian limes from Sandusky, Ohio, and from Sheboygan, Wisconsin.

17. The impurities in lime all have some influence on its properties. The presence of very small amounts of iron tends to color the lime red or yellow, while manganese makes it gray or black. Silica decreases the plasticity of lime and its sand-carrying capacity, but alumina on the other hand increases these properties. When lime is to be used for building purposes it may contain a somewhat larger amount of impurities than when used for plaster finishing and chemical purposes. Many limes which contain from 5 per cent. to 10 per cent. impurities find extensive local use. Some of the lime sold locally for fertilizer is very impure, containing often only 65 per cent. of lime. Where lime is shipped any distance, however, it is usually quite pure.

Lime is employed for many purposes besides building. It is used for water softening, for purifying coal gas, in tanning leather, in the manufacture of sugar, wood-paper pulp, glass, calcium carbide, bleaching powder, lye, and other chemicals. For most of these purposes a high-calcium lime is required, although both kinds are used for fertilizer, and dolomitic lime is preferred for wood-pulp manufacture. For all of these purposes the value of the lime increases with its purity.

HYDRATED LIME

18. Dry ready-slaked lime is sold under the name of *hydrated lime*. The advantages possessed by hydrated lime over quicklime are numerous. It is more conveniently handled and cheaply shipped, as it is packed in bags. It will keep much better, as it does not air-slake. There is no risk of fire due to the heat which will be liberated when water accidentally reaches quicklime in storage. It is ready for use at all times, being, if properly prepared, thoroughly slaked. It can also be conveniently mixed with cement, rendering the latter waterproof and more plastic.

If lime is free from impurities it will take up 32.1 per cent. of water.   Lime in slaking liberates 485 B. T. U. per pound
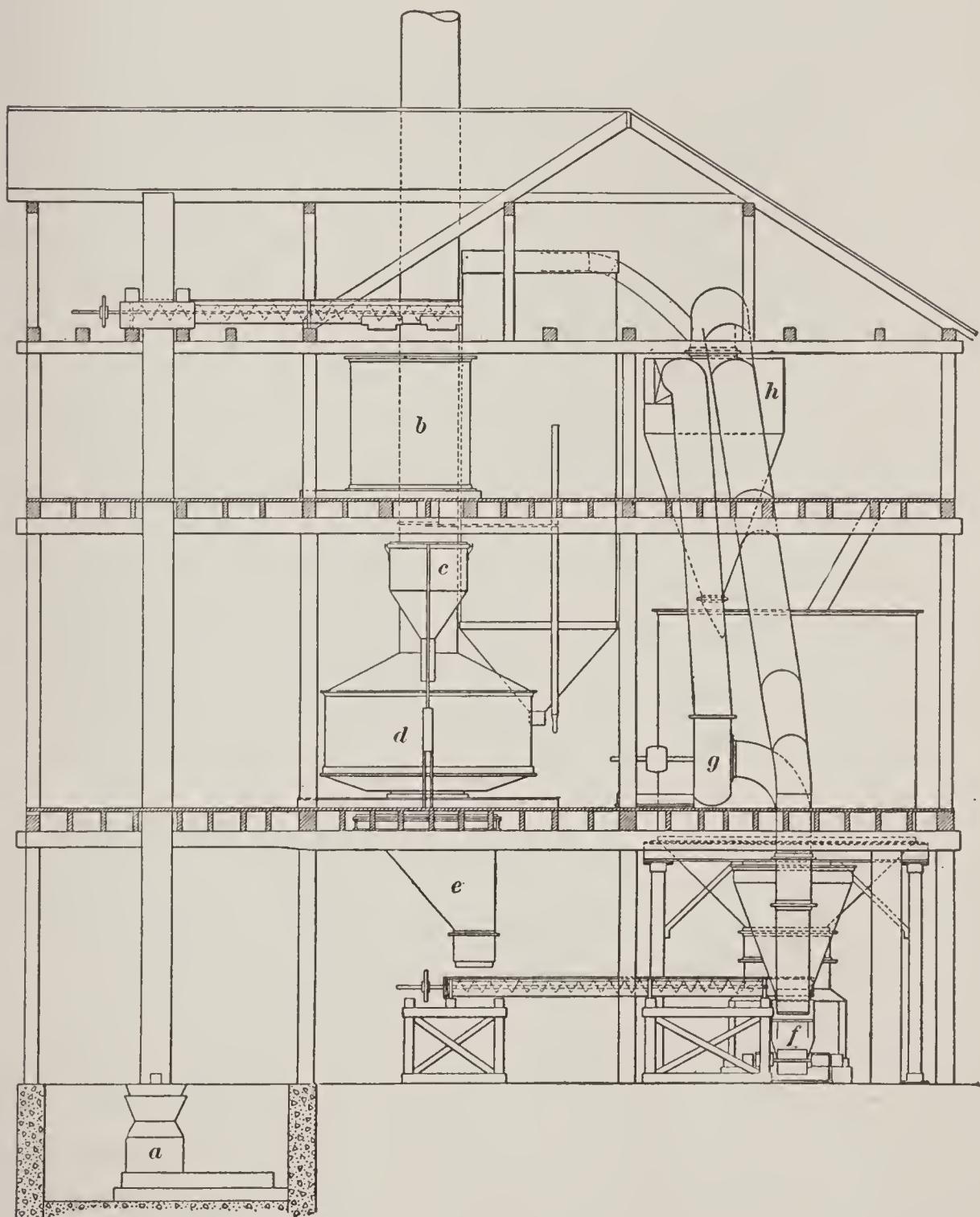
FIG. 4

of lime hydrated.   This heat is sufficient to evaporate about $\frac{1}{2}$ pound of water.   It will be seen, therefore, that if to 1 pound

of lime about .8 pound of water is added, about .3 pound of this water will enter into combination with the lime and the other .5 pound will be evaporated by heat produced by the combination of the lime and water, leaving a dry powder consisting of calcium hydrate. In practice some heat is lost in radiation, so the amount of water which can be added is somewhat below .8 pound per pound of lime. It usually is not greater than .6 pound in the case of high-calcium limes, and in the case of magnesian limes is still less, as all of the magnesium oxide is not converted into hydrate. Hydrated lime is a fine powder practically all of which will pass a No. 100 test sieve. It is packed in burlap or cloth bags holding 100 pounds or in paper bags holding 50 pounds.

19.   Process of Manufacture.—In the process of manufacture the quicklime is first crushed to about $\frac{1}{2}$ inch and under, or even finer. It is then mixed with water just sufficient to hydrate all the lime and yet not so much that the heat of slaking will not evaporate the excess, when it falls to a dry powder. The slaked lime is then ground to break up clots of hydrate, and the coarse particles are separated out by means of an air separator.

Fig. 4 shows a hydrated-lime plant. In this the lime is first passed through a Sturtevant open-door crusher a. This works on the same principle as an ordinary coffee grinder and reduces the lime to such a size that it will all pass through a $\frac{1}{2}$-inch screen. This is fine enough for hydrating purposes. From the crusher the lime is elevated into a large bin b in the top of the building. The bottom of the bin is provided with a spout and gate, the latter being opened and closed by a lever. Below the spout is located a weighing hopper c, and beneath this, the hydrator d. The hydrator is a Clyde hydrator. This machine is shown in detail in Fig. 5 and consists of a revolving pan a provided with plows b, which stir up and mix the water and the lime. The pan is revolved by means of a gear c and pinion located on the under side of the pan. The pan is covered by means of a hood d and a stack f leading through the roof of the building. The hood does not revolve. In the center of the

pan is a metal rim *g* which closes a circular opening. The rim *g* is raised, exposing the opening, by the wheel *h* and axle, and the hydrate when finished is discharged through this opening. The hydrator rests on the second floor and the scale box, valve, and indicator to the water tank are also on this floor, so that all the operations of the hydrator are controlled at one point. The lime is weighed out in batches of 1,800 to 2,500
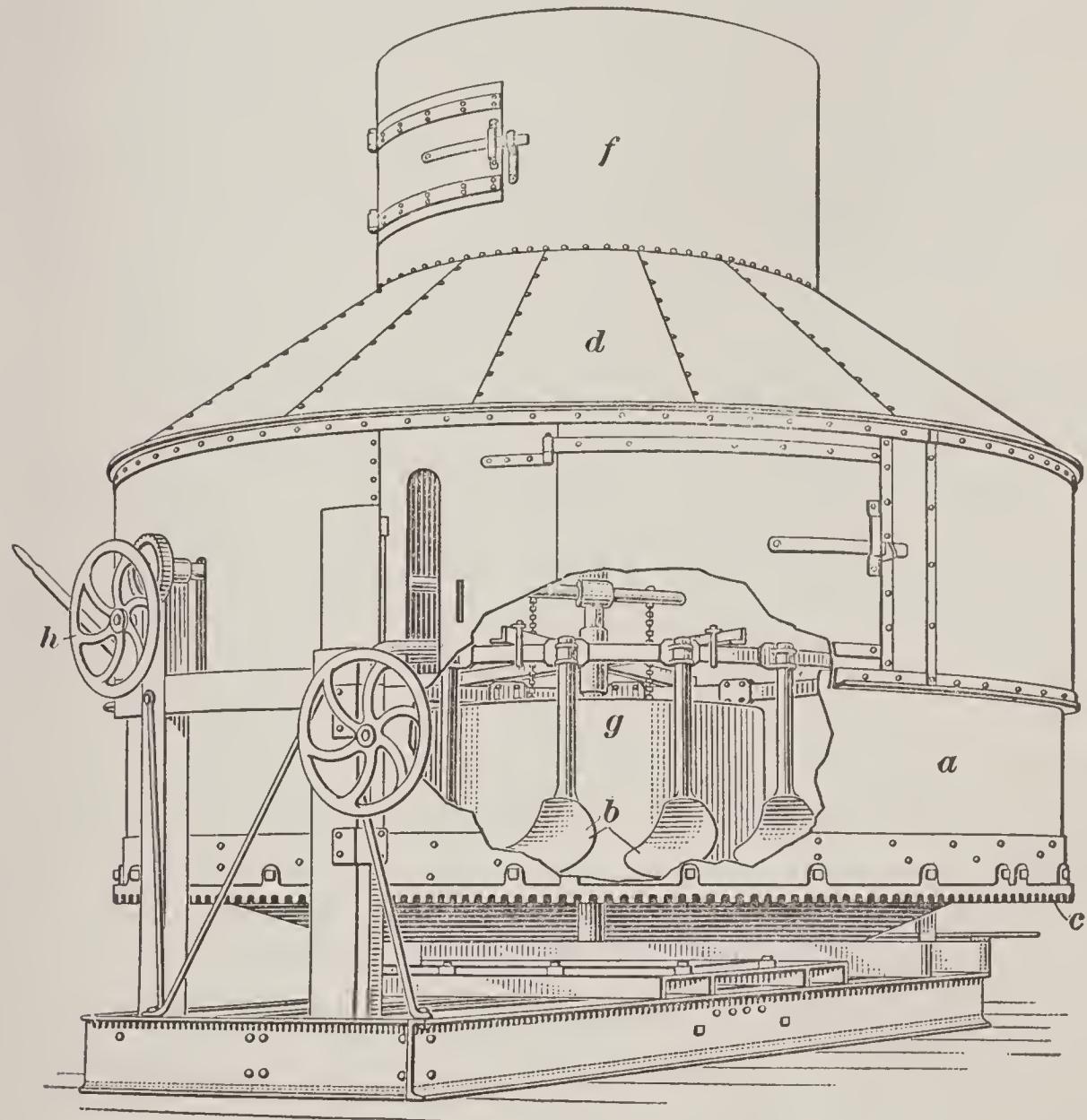
Fig. 5

pounds and dumped directly from the scale hopper into the hydrator. The water is measured in a tank which is beside the lime bin.

The process of hydration consists in first weighing out the lime, measuring the water, dumping the lime into the hydrator, and then spraying the water on the lime. The lime is usually

stirred for some time after all the water has run out of the tank in order to allow the steam to escape. At first the lime is very wet, but as chemical combination takes place it dries out and falls to a fine powder, the charge swelling up greatly. The whole operation lasts from 15 to 20 minutes. When the operator judges the hydration to be complete, the lime is dumped into a large bin or hopper *e*, Fig. 4, by means of a valve in the center of the hydrator capable of holding comfortably the charge from the hydrator. This hopper is of steel and is provided with an automatic feeder at the bottom. This feeder serves to regulate the supply of lime going from the hydrator to the pulverizer and is so adjusted as to supply the pulverizer at the proper rate. The lime usually falls from the feeder into a screw conveyer which carries it to the pulverizer.

20. After slaking the lime is in the form of a very fine fluffy powder mixed with occasional larger pieces, or *cores*. These cores consist of unburned limestone, silicious matter which has been partly vitrified, and overburned lime which has not been hydrated. The two latter substances, if left in the lime, will cause trouble, because when this lime is used for plaster they will not slake immediately when mixed with the water, but will eventually do so. When lime slakes, expansion occurs, and hence wherever there is one of these cores in the wall a blister occurs. It is necessary, therefore, either to grind these cores so finely that they will hydrate at once when water is added to them, or, which is better, to separate them from the hydrate.

For treatment of the lime after passing through the hydrator the Raymond system is almost universally employed. This system consists of three parts, a pulverizer, a fan, and a collector. The lime first goes to the pulverizer located on the ground floor. The pulverizer is equipped with an automatic throw-out. This latter separates any cores from the hydrate. From the pulverizer the fine product is sucked by means of a fan and blown into a dust collector. This collector is located above the packing bin and the hydrate falls from the collector into the packing bin. The packing is

done by means of Bates packers, and Bates valve bags are used. This system will be described later.

21. There are several other types of hydrators on the market. The Schaffer hydrator consists of a series of pans one above the other. Plows revolve in the pans and mix the water and the lime. The lime and water are fed into the top pan and the hydrate works its way out at the bottom, etc. The Kritzer hydrator consists of a number of cylinders one above the other which are provided with paddles which revolve around a central shaft and stir the lime and water. The lime is fed into the top cylinder where the water is added, and the hydrate is discharged from the bottom cylinder. Both the Schaffer and Kritzer hydrators are continuous while the Clyde is a batch machine.

In place of the Sturtevant mill shown the lime may be crushed by means of hammer mills or rolls. If the cores are ground with the hydrate, instead of being separated from it, the crushing is done by passing the hydrate through a pulverizer mill. Tube mills and Fuller mills have been used for this purpose. Some of the older mills employ shaking screens instead of air separators to remove the cores.

SAND-LIME BRICKS

22. The term *sand-lime bricks* is applied to bricks that are made by mixing sand with a small percentage of slaked lime. The mixture is then pressed into molds and the product hardened either by artificial or sun heat. The process is an old one that has recently been revived, many patents covering various details of the process having been granted during the past few years.

In most modern plants the material used in these bricks is clean, usually white, quartz sand free from clay and containing considerable fine material. All the sand should pass a 20-mesh sieve and at least 10 or 15 per cent. of it should pass a 100-mesh sieve. The strength of the bricks will in a large measure depend on the amount of fine sand in the mixture, the weakest bricks containing the largest percentage of very fine

sand. In making the bricks the sand is dried and mixed with 5 to 10 per cent. of slaked lime which should be free from oxide of iron in order not to color the bricks, and very carefully slaked. Water is then added to the mixture and the material pressed into shape in a mold by a pressure of 200 to 250 tons per brick. The bricks are then loaded on trucks and run into a large horizontal cylinder that can be tightly closed. Here the bricks are hardened by subjecting them to steam under pressure for a period of time depending on the pressure, 6 hours being sufficient to harden the bricks when steam at a pressure of 150 pounds is employed.

Bricks of this kind have a crushing strength of 3,500 to 5,000 pounds per square inch, but are neither so dense nor so strong as good, well-made clay bricks.

HYDRAULIC LIMES

23. The term *hydraulic lime* is applied to those cementing materials which contain sufficient silica and alumina to give them hydraulic properties and yet enough free lime to make them slake on the addition of water. Compared with Portland and natural cements, hydraulic limes are only feebly hydraulic. Therefore they are almost unknown in the United States, where an abundance of material for the manufacture of cement exists. As the cost of manufacturing cement is only a trifle greater than that of manufacturing hydraulic lime, and as cement is by far the best of the two, it is unlikely that hydraulic limes will ever be manufactured to any extent in the United States. In France and other parts of Europe, however, the making of hydraulic lime is an important industry. The limestones used in the manufacture of hydraulic limes usually contain between 70 and 85 per cent. of calcium carbonate. The percentages of iron and alumina are usually low and rarely exceed 3 per cent.

24. Calcination.—The calcination of hydraulic limes is accomplished in shaft kilns similar to mixed-feed lime kilns, coal or coke being the fuel commonly used. Before being

charged the rock is broken into pieces about the size of the head, in order to facilitate burning and to prevent too large an amount of undecomposed carbonate. No grinding machinery is used either before or after burning, as a good hydraulic lime should fall to powder when slaked. The slaking is, of course, much slower than with quicklimes. The composition of the raw material may also be such that, when calcined at a low temperature, it will yield a product whose chemical analysis closely resembles that of Portland cement.

25. Graphier Cements.—What are known as *graphier cements* are made by grinding finely the lumps of under-burned and overburned material that remain after a hydraulic lime is slaked. Since the underburned portions are merely

TABLE III

COMPOSITION OF HYDRAULIC LIMES AND GRAPHIER CEMENTS

Material	Loss on Ignition Per Cent.	SiO_2 Per Cent.	Al_2O_3 Per Cent.	Fe_2O_3 Per Cent.	CaO Per Cent.	MgO Per Cent.	SO_3 Per Cent.
Hydraulic lime (German)	5.24	32.60	7.17	6.23	44.96	1.52	1.20
Hydraulic lime (French)	8.55	21.60	2.00	1.25	65.80	1.35	.15
Graphier cement, La-farge (French)......	1.28	31.10	4.43	2.15	58.38	1.09	.60
Graphier cement, Mier's (German)....	7.93	23.90	6.86		58.49	1.00	1.49

limestone the value of the cement will depend on the relative proportions of overburned and underburned material in the mixture. If nearly all the cement consists of overburned material the resulting cement is almost as good as Portland cement. Graphier cements contain practically no soluble sulphates, and consequently they do not stain masonry. The non-staining cements, such as the brand known as Lafarge, now imported into the United States, are graphier cements.

26. Composition of Hydraulic Limes.—In Table III are given the compositions of two foreign non-staining graphier cements, and of several hydraulic limes.

PLASTERS

27. Gypsum.—When pure the mineral gypsum is a hydrous sulphate of calcium having the formula $CaSO_4 + 2H_2O$ and consisting of 32.6 per cent. of lime, CaO, 46.5 per cent. of sulphur trioxide, SO_3, and 20.9 per cent. of water. As quarried, however, gypsum usually contains more or less impurities, the chief ones being carbonates of calcium and magnesia, silica, oxide of iron, and alumina. Alabaster, which is sometimes used for statuary, is a pure white, fine-grained gypsum. Anhydrite, $CaSO_4$, closely resembles gypsum, but it contains no water, hence its name. It cannot be used for the manufacture of plaster of Paris or wall plaster.

Pure gypsum is white and in the crystalline form is translucent. As quarried or mined, however, gypsum is usually opaque and colored from impurities. It has a specific gravity of 2.3 and occurs in beds, being frequently found associated with rock salt and almost always mixed with beds of limestone and red shale. Gypsum deposits were formed under water by the gradual evaporation of lakes, etc., whose waters contained calcium sulphate. Workable deposits of gypsum in the United States were formed chiefly during three geological periods, the Silurian, the Lower Carboniferous, and the Permian. Large quantities of very pure gypsum are imported into the United States from Nova Scotia and New Brunswick.

28. Plaster of Paris.—If gypsum is heated to a temperature between 212° and 400° F., 75 per cent. of the water of crystallization that it contains will be driven off, and the resulting compound known as *plaster of Paris* will have the formula $(CaSO_4)_2 H_2O$ and will be composed of 93.8 per cent. of calcium sulphate, $CaSO_4$, and 6.2 per cent. of water.

If gypsum is heated to a temperature above 400° F., all its water will be driven off and it will become anhydrous calcium sulphate, $CaSO_4$. Plaster of Paris is manufactured on a large scale in the United States, the process consisting in grinding the gypsum to a fairly fine powder, calcining this powder at a temperature between the limits indicated, and

then sieving and if necessary regrinding the coarse particles. The general steps in the process are shown in Fig. 6.

As it comes to the plaster mill, the lump gypsum is first crushed to a size of 2 to 4 inches by means of a gyratory or toggle-joint crusher such as is used for breaking stone for ballast and road-making purposes.   The   product   of   the
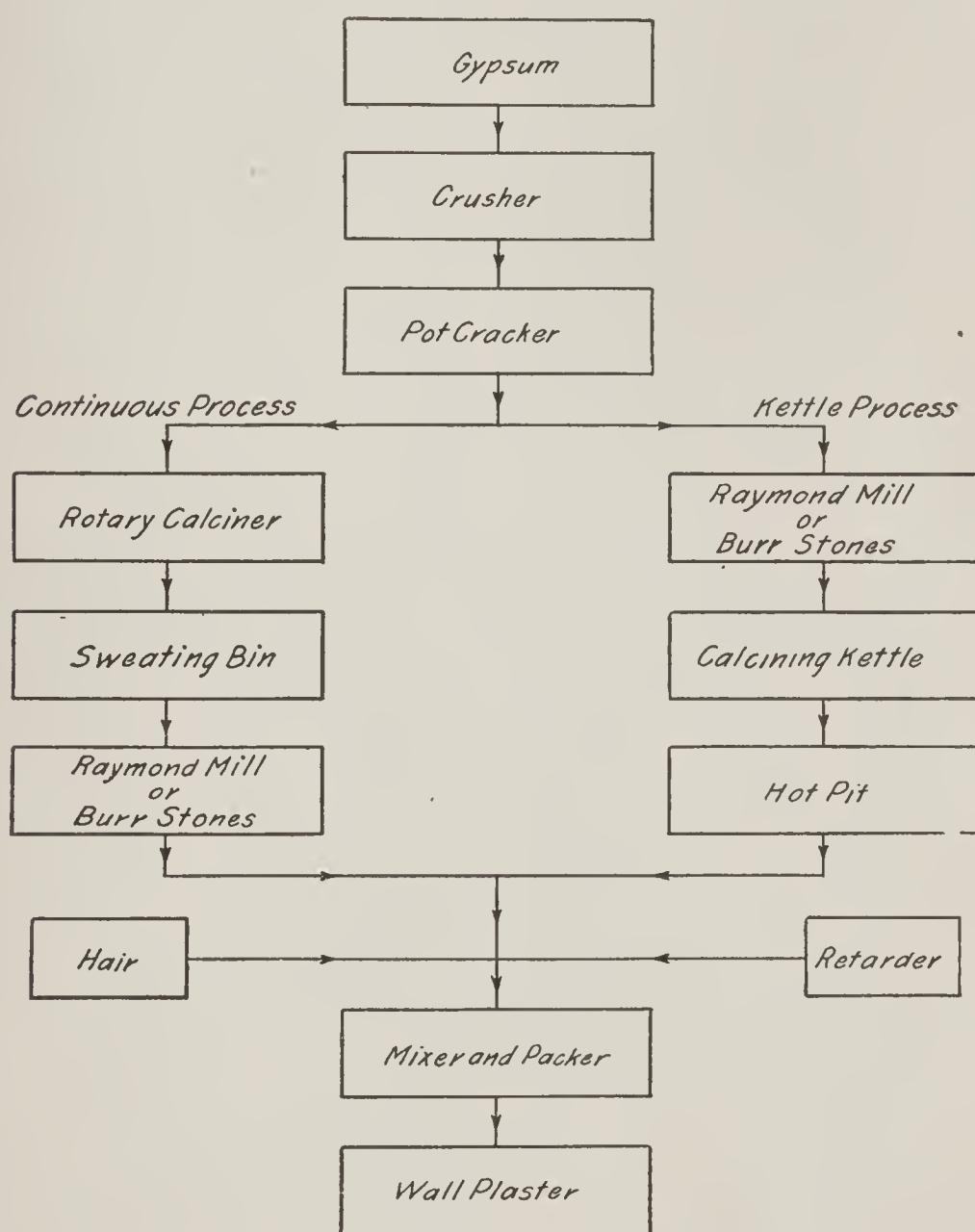
FIG. 6

crushers is then sent to the crackers, which work on the same principle as an ordinary coffee mill. The cracker shown in Fig. 7 consists of a central shaft *a* actuated by means of overhead gears *b*. This shaft has securely fastened to it two burrs, the upper of which, *c*, has coarse teeth and the lower, *d*, fine corrugations. These two burrs revolve inside of two cone-

shaped receptacles *e* and *f*. The upper of these has coarse teeth and the lower has corrugations. It will be noted that the space between the burrs and the cones gets less as the bottom is reached. The material is fed into the upper cone or hopper and works its way down and out. These crackers
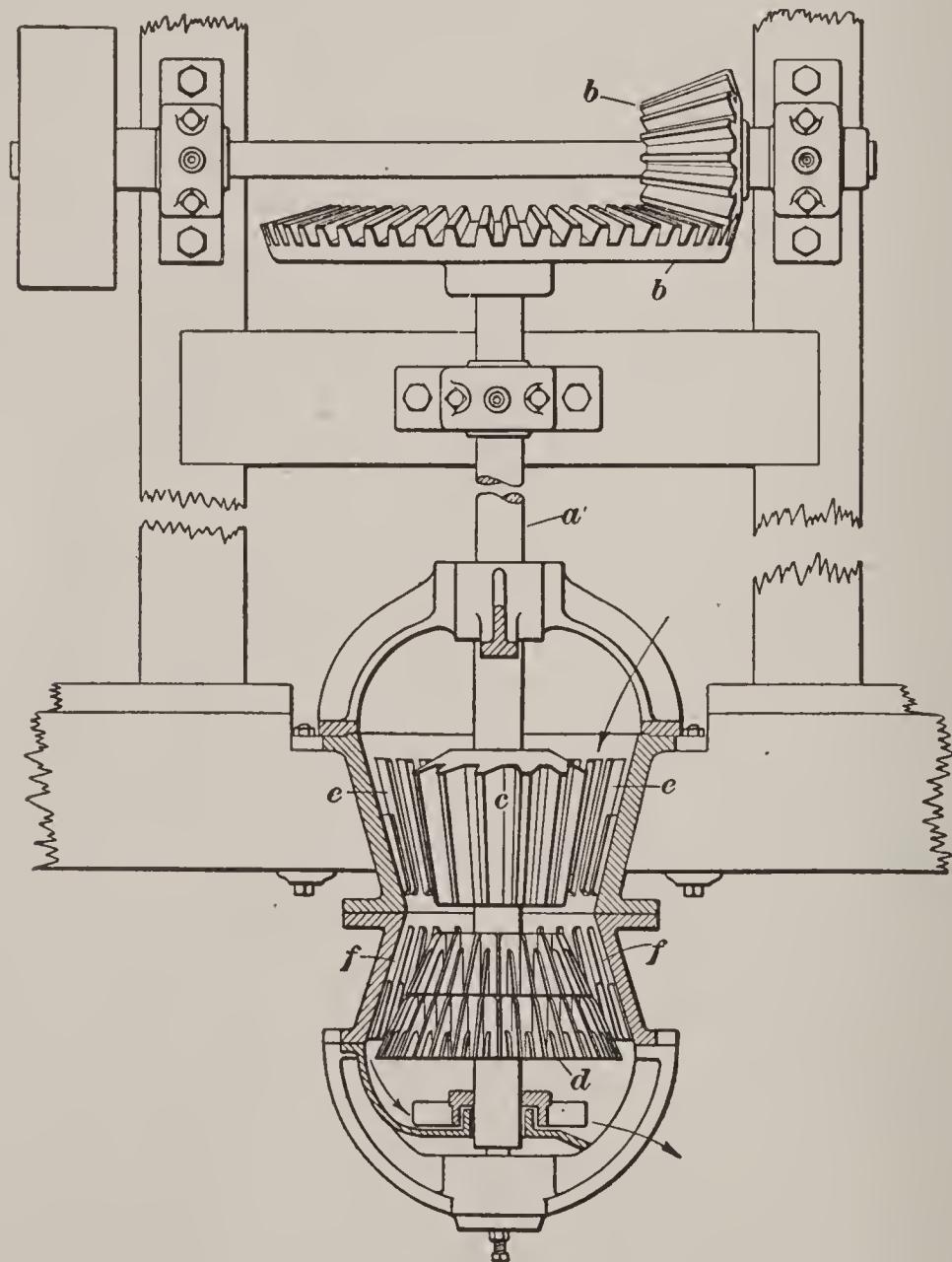
Fig. 7

reduce the gypsum to pieces about ½ inch or smaller. From the crackers the materials pass to the fine grinders, which consist of rock-emery mills or sets of burrstones. These reduce the gypsum to such a size that from 50 to 75 per cent. of it will pass a 100-mesh sieve. After being ground to this fineness the gypsum is ready for calcining.

29. The calcining of gypsum is usually done in kettles. The kettle, shown in Fig. 8, consists of a cylinder a of sheet steel 8 or 10 feet in diameter and 6 or 8 feet deep, with a convex bottom of cast iron. This device has two or four horizontal 12-inch flues b, b that are placed about 8 inches from the crown of its bottom and about 6 inches apart. It is also
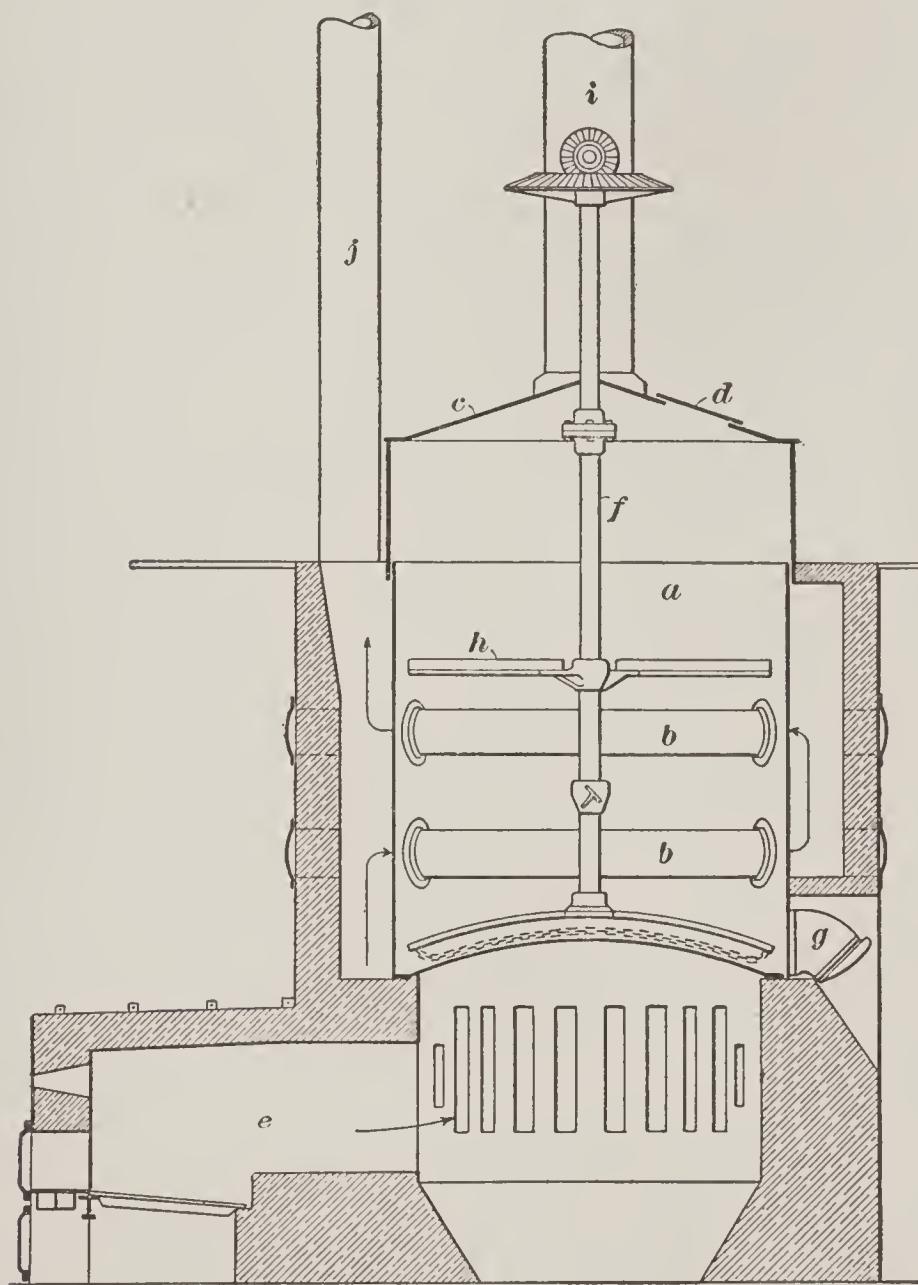
provided with a top c that has a door d through which the ground gypsum is introduced. The kettle is mounted on a masonry fireplace e and is partly surrounded by masonry so that the products of combustion pass through the flues. As the gypsum must be kept continually agitated to prevent caking and the burning out of the kettle bottom, the kettle is

provided with a stirrer. This latter consists of a vertical shaft f attached to which are two cross-arms, the one, h, being straight and the other, at the bottom, being curved. These cross-arms act as the stirrers. Both the kettle and firebox are provided with stacks i and j, respectively. The kettles are provided with ports or openings g through which the calcined gypsum may be discharged. The kettles hold from 7 to 12 tons of gypsum and from 10 to 25 horsepower is required to run the stirrer. The process of calcining requires from 2 to 3 hours.

In calcining gypsum the material is fed into the kettle a little at a time until it is full, and as the temperature rises to about 220° F., the contents of the kettle boils just as water does, until the water or moisture that is held mechanically is all driven off. The temperature is then raised to about 300° C., when the chemically combined water begins to come off, and at from 350° to 400° C. the process is complete. The expelled water is led off by means of a stack set into the top of the kettle and the calcined material is run into a fire-proof pit where it is allowed to cool slightly. It is then screened through a revolving separator made of wire cloth, and the coarse material is reground by burrstones.

Burrstones are not very efficient grinding machines and modern engineers are gradually replacing them with more efficient machines. The burrstones not only take more power than other pulverizers but they also do not grind as fine and the dressing of the stones themselves requires considerable skill and time. In the newer plaster mills the grinding of the gypsum is done by means of Raymond roller mills and the material is ground to its ultimate degree of fineness before being introduced into the kettles. The Raymond roller mill requires that the gypsum be dried before being ground and this drying is done in rotary driers similar to those used in cement mills. The gypsum after being dried is ground to the fineness required of the finished plaster, then it is calcined, and after cooling it is ready for use.

The finer the plaster is ground, the better it is. Usually, however, it is not ground finer than about 85 per cent. pass-

TABLE IV
COMPOSITION OF PLASTER MATERIALS

Materials	Silica, SiO_2 Per Cent.	Oxide of Iron and Alumina, $Fe_2O_3+Al_2O_3$ Per Cent.	Lime, CaO Per Cent.	Magnesia, MgO Per Cent.	Sulphur Trioxide, SO_3 Per Cent.	Carbon Dioxide, CO_2 Per Cent.	Water, H_2O Per Cent.
Gypsum, Kansas	.35	.12	32.49	.12	46.30	.17	20.52
Gypsum, Nova Scotia	.11	trace	32.90		46.12	.47	20.43
Gypsum, New Brunswick	.10	.10	32.35		46.20		20.94
Plaster of Paris, Kansas	11.97	.67	83.96	.34	42.01	3.96	6.98
Plaster of Paris, Kansas	.85	.16	38.04	.60	53.56	1.09	6.33
Keene's cement	trace	trace	42.04	trace	56.54	1.37	trace

ing the No. 100 sieve. A four-roller Raymond mill will grind 4 to 5 tons of gypsum per hour to this fineness. When burrstones are employed a 42-inch stone is usually employed for the raw gypsum and a 36-inch stone for grinding the rejects from the screens, which are usually of the shaking type. A combination of 42-inch and 36-inch burrstones will grind about 2 tons per hour to a fineness of 80 per cent. passing the No. 100 sieve.

The coal required to calcine gypsum is usually between 80 and 90 pounds per ton of plaster produced. Less coal is required when the gypsum is dried before being ground.

30. Gypsum is also calcined in rotary driers. These consist of cylinders of sheet steel mounted on rollers. The gypsum is heated in these cylinders to about 400° F. and while at this tem-

perature it is elevated into bins where the residual heat in the material completes the calcination. The driers used are similar to those employed for drying coal and rock in the manufacture of Portland cement and are described in detail later. The rotary process differs from the kettle process of calcination in this respect that the gypsum is merely crushed to a size that will pass a 1-inch ring screen before being calcined, after which it is ground to the required fineness.

31. Cement Plaster.—If the gypsum used for making plaster of Paris is pure the calcined product will set very

TABLE V
STRENGTH OF FINISHING PLASTERS

Kind of Plaster	Age of Briquettes		
	1 Day	7 Days	28 Days
	Tensile Strength in Pounds per Square Inch		
Plaster of Paris, neat	228	393	445
1 part plaster of Paris and 1 part sand	87	320	368
1 part plaster of Paris and 2 parts sand	55	203	212
1 part plaster of Paris and 3 parts sand	35	148	145
Keene's cement...........	367	669	

rapidly when mixed with water. If, however, the gypsum contains a large percentage of impurities the resulting plaster will set more slowly. The same result can also be obtained by adding certain retarders to plaster of Paris made from pure gypsum. Since a slow-setting plaster can be handled more conveniently than a quick-setting one, it is customary to add 2 to 10 pounds of some retarder to every ton of plaster and the resulting product is generally marketed as cement plaster

stucco. The materials used as retarders are usually of an organic nature, as glue, sawdust, blood, packing-house tankage, etc., and are non-crystalline in character. Colloidal, or non-crystalline, substances, such as clay, etc., can also be used as retarders. Hence, gypsum containing clay makes a slow-setting plaster.

32. Wall Plaster.—Cement plaster to which has been added a certain percentage of fine picked hair in about the proportion of 2 or 3 pounds of hair to a ton of plaster, is known as *wall plaster*. In place of hair wood fiber is now used a great deal, about 75 to 150 pounds of the fiber being added to a ton of plaster.

33. Hard-Finish Plaster.—In manufacturing hard-finish plasters, gypsum is completely dehydrated by heating to a high temperature. The calcined material is then immersed in a solution of alum and after drying it is again calcined at a red heat. The resulting product is ground very finely, when it is ready for the market. Chief among the hard-finish plasters is Keene's cement, which was originally manufactured in England but on which the patents have expired.

34. Composition and Tests of Plasters.—Table IV gives the composition of several samples of gypsum, plaster, etc., and Table V gives the strength of several finishing plasters.

CEMENTS

NATURAL, ROMAN, AND ROSENDALE CEMENTS

COMPOSITION AND PROCESSES OF MANUFACTURE

35. Classification.—Strictly speaking, natural, Roman and Rosendale cements all belong to one class, their compositions and the process of their manufacture being similar. They are frequently erroneously called *hydraulic*. This is a misnomer, since slag and Portland cements are also hydraulic, but they are very different from natural or Rosendale cement, both in composition and properties. Natural cement is somewhat similar to hydraulic lime. Instead of slaking with water, however, after burning it is pulverized, exposed to the air to season and then put on the market in powdered form. Instead of having a loss on ignition of 8 to 21 per cent. as in hydraulic limes, this loss is less than 5 per cent. and the resulting cement is much stronger. In a strict sense the name *Rosendale* is a local one, being applied originally only to cements from the cement district of Ulster County, New York. Other manufacturers in various sections of the country coming into the market later with similar products used the name *Rosendale*, whereas *Natural* or *Roman* would have been better.

36. Composition and Properties of Natural Cements.—Natural cements made from American rocks will show a specific gravity of 2.8 to 3.15, a little lower than the specific gravity of Portland cement. The natural cements set much more rapidly than Portland cements, but their setting time may be retarded to some extent by the addition of plaster of Paris, or by aeration. They should require at least 10 minutes to gain their initial set and should be hard-set in 3 hours. They harden much more slowly than Portland cement, but

TABLE VI
COMPOSITION OF VARIOUS NATURAL CEMENTS

Brand	Where Made	Silica, SiO_2 Per Cent.	Alumina, Al_2O_3 Per Cent.	Iron Oxide, Fe_2O_3 Per Cent.	Lime, CaO Per Cent.	Magnesia, MgO Per Cent.	Alkalies, K_2O+Na_2O Per Cent.	Loss, CO_2+H_2O Per Cent.
Howard.............	Georgia	22.56	7.23	3.35	48.18	15.00		
Utica..............	Illinois	27.60	10.60	.80	33.04	17.26	7.42	2.00
Hulme Star........	Kentucky	25.28	7.85	1.43	44.65	9.50		7.04
Cumberland........	Maryland	29.92	11.23	4.78	36.50	11.63		5.42
Hoffmann..........	New York	28.91	10.96	4.68	34.64	14.82	1.80	4.50
Akron Star........	New York	20.20	4.40	2.80	41.60	22.24	1.62	6.90
Bonneville Improved	Pennsylvania	30.40	10.36	2.60	52.12	.21		3.07
Milwaukee.........	Wisconsin	25.00	4.00	2.80	33.40	22.60	2.51	9.50

develop very good strength in time. They are not usually so finely ground nor can they be used for the better grades of concrete work.

Table VI gives the composition of some of the best known American cements.

37. Natural-Cement Rock.—The rock from which natural or Roman cement is manufactured consists of an impure limestone containing from 20 to 30 per cent. of clay. It is necessary that this limestone should be of uniform composition and very fine grained. The mixture of calcium carbonate and clay must be very intimate and no rock made up of bands of pure limestone and shale or slate is suitable for the manufacture of natural cement no matter what its average analysis may be. Magnesium carbonate up to 30 per cent. may be present in the rock; natural cements made from low magnesian rock, however, are just as good as those made from magnesian limestone.

38. Process of Manufacturing Natural Cement. The process of manufacturing natural cement differs materially from that of making Portland cement. Except possibly for crushing by sledges and sorting into coarse and fine, the raw material undergoes no preliminary preparation before burning, but is taken from the quarry or mine directly to the kilns. After burning and grinding the cement is ready for use. For burning the raw material the kilns are of the vertical type and are simple in construction and similar to the mixed-feed lime kilns. The operation of burning is the same as for lime, anthracite coal being employed as a fuel.

As the rock is calcined at a low temperature the amount of fuel used is small, varying with improved kilns from 6 to 15 per cent. of the weight of cement produced. The material drawn from the bottom of the kiln is sometimes sorted, the hard or overburned pieces being discarded and the remainder put through grinding mills. More often, however, the entire product is ground and sent to the stock house or the packing house. A kiln of the dimensions indicated in Fig. 1 produces from 90 to 100 barrels of cement per day.

39. Pulverizing Natural-Cement Rock.—The machinery for pulverizing natural-cement rock after burning differs from that described later in connection with the Portland cement-making process, the ball mills or Griffin mills, which are indispensable in Portland cement plants, being used only in plants producing both Portland and natural cement. There are two reasons for this: first, the lightly burned rock
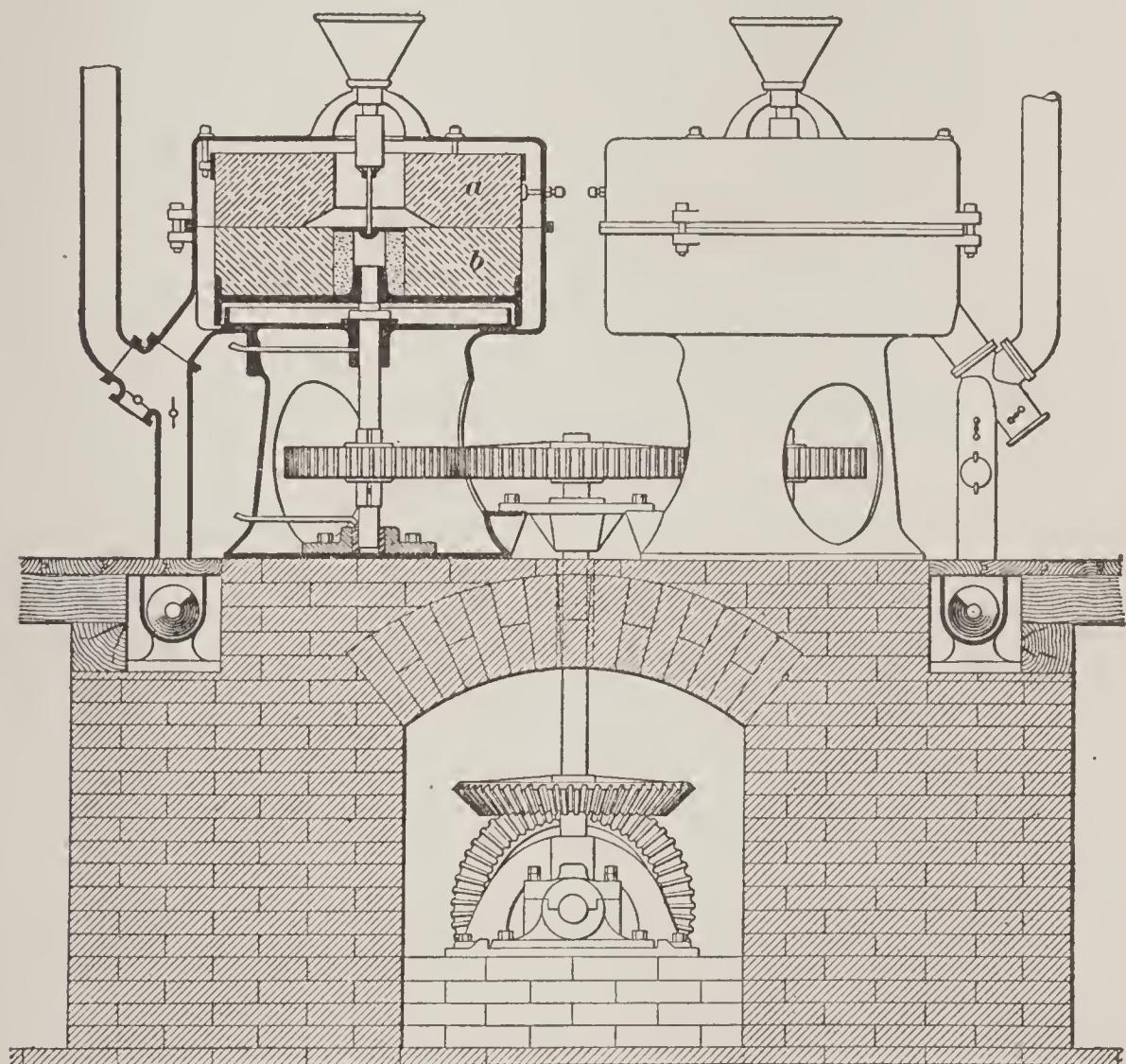
Fig. 9

corresponding to clinker in the Portland process, is much more readily ground than clinker; second, the requirements as to fineness are not so rigid as for Portland cement. A common practice in grinding is to put the burned rock through vertical crackers similar to coffee mills which reduce about 25 per cent. of the material to a merchantable fineness. This is separated by screens and sent to packers. The remainder

is pulverized to the required fineness by the old-fashioned burr-stone mill, or by rock-emery mills.

The burrstone mill, as shown in Fig. 9, consists of two stones *a* and *b* with dressed faces, the lower one *b* revolving and grinding the cement between it and the stone *a*. Each millstone usually consists of one piece of burrstone or quartzite. From time to time the stones are redressed and furrows running radially are cut in the stones to facilitate grinding.

The rock-emery mill is similar to the burrstone, but, as the name indicates, rock emery is used for the grinding surfaces.

POZZULAN CEMENTS

40. Pozzulanic Materials.—The materials used in the manufacture of pozzulan cement may be of either natural or artificial origin, consisting of those substances which are

TABLE VII
COMPOSITION OF POZZULANIC MATERIALS

Material	Silica, SiO_2 Per Cent.	Alumina, Al_2O_3 Per Cent.	Iron Oxide, Fe_2O_3 Per Cent.	Lime, CaO Per Cent.	Magnesia, MgO Per Cent.	Soda, Na_2O Per Cent.	Potash, K_2O Per Cent.
Pozzulan	42.00	15.50	12.50	9.47	4.40		
Trass	48.93	18.95	12.34	5.40	2.31		
Santorin earth......	66.37	13.72	4.31	2.98	1.29	4.22	2.83
Blast-furnace slag	32.28	12.50	5.14	48.00	2.00		

capable of forming hydraulic cements simply by being mixed with lime. No heating or further treatment is necessary. The natural pozzulanic materials are widely distributed and usually consist of fine volcanic ash or dust (pozzulan, trass, santorin) deposited either on the slopes of a volcano or carried by the winds to lakes or streams and deposited there. The word *pozzulan* comes from the little town of Pozzuoli at the foot of Mount Vesuvius where the volcanic ash was obtained by

the Romans for their cement. This volcanic ash resembles blast-furnace slag in composition, as indicated in Table VII.

Natural puzzolanic materials of domestic origin have never come into use and only a very little cement made from such natural materials has been imported into the United States. Of all the puzzolanic materials blast-furnace slag is by far the most important.

41. Process of Manufacturing Pozzulan Cement. What is known as *slag cement* is made by granulating slag as it runs from the furnace by means of a jet of water; it is then dried in revolving dryers, mixed with the proper propor-

TABLE VIII
COMPOSITION OF SLAG CEMENTS

Source of Samples	Silica, SiO_2 Per Cent.	Iron Oxide and Alumina, $Fe_2O_3 + Al_2O_3$ Per Cent.	Lime, CaO Per Cent.	Magnesia, MgO Per Cent.	Sulphur, S Per Cent.	Loss on Ignition Per Cent.
Chicago, Illinois....	27.20	14.18	50.03	3.22	1.40	4.25
Chicago, Illinois....	29.80	12.30	51.14	2.34	1.37	2.60
Chicago, Illinois....	27.80	11.10	50.96	2.23	1.18	5.30
North Birmingham, Alabama.........	27.00	12.00	55.00			
Ensley, Alabama....	27.78	11.70	51.71	1.39	1.31	

tion of slaked lime, and ground so fine that from 90 to 95 per cent. of the product will pass through a 200-mesh sieve. This powder is the finished product.

Not all slags are adapted to the making of cement. The composition of such slags must lie within the following limits: Silica, not over 49 per cent.; alumina, from 12 to 17 per cent.; magnesia, under 4 per cent.

42. Properties and Composition of Slag Cements. Slag cements set very slowly and accelerators are usually added to quicken the set. In the Whiting process caustic soda and potash or sodium chloride are added for accelerating purposes. Slag cements are usually much lighter in color than

Portland cement, varying from bluish-white to yellow, and they also have a much lower specific gravity—from 2.7 to 2.8. Slag cements show good tensile strength when tested with sand, but have slight resistance to abrasion, or, in other words, wear poorly and are therefore unsuited for making floors, sidewalks, etc. The slag cements are also considered much better for use under water than in dry air.

Table VIII gives the composition of some slag cements.

PORTLAND CEMENT

CHARACTER AND COMPOSITION

43. What is commonly known as *Portland cement* may be defined as the finely pulverized product resulting from the calcination to incipient fusion of an intimate mixture of properly proportioned argillaceous and calcareous materials and to which no addition of other material greater than 3 per cent. is made subsequent to calcination. The general steps in the process of manufacture are shown in Fig. 10.

44. Composition of Portland Cement.—The average composition of a number of American Portland cements is given in Table IX.

The essential elements of Portland cement are silica, alumina, and lime. A small amount of the alumina is always replaced by iron, however, and some of the lime by magnesia owing to the presence of these elements as impurities in the raw materials. Calcium sulphate in the form of gypsum or plaster of Paris is always added to regulate the set. Carbon dioxide and water, usually reported together in an analysis and called *loss on ignition,* are gradually absorbed by the cement during grinding and in storage.

45. Influence of Lime.—Portland cement usually contains from 60 to 64 per cent. of lime. Up to a certain limit it may be said that the more lime there is present in the cement the greater will be its strength. The limit is reached, how-

ever, when more lime is present than will combine chemically with the silica and alumina, thus leaving some lime in the uncombined state. Lime in slaking expands so that an excess of lime over what will unite with the silica and alumina will cause the cement to expand, or *blow,* as it is technically termed, and crack. High-lime cements are usually very slow-setting but they harden rapidly, sometimes reaching their maximum


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┌─────────────────────┐          ┌─────────────────────┐
│ Limestone, Marl     │          │ Clay, Shale, Slag   │
│ or Chalk            │          │ or Cement Rock      │
└─────────────────────┘          └─────────────────────┘

          ┌───────────────────────────┐
          │ Mixed in proper           │
          │ proportions as            │
          │ shown by analysis         │
          └───────────────────────────┘

          ┌───────────────────────────┐
          │ Pulverized to a fineness  │
          │ of 90 to 95 % passing     │
          │ the No. 100 sieve         │
          └───────────────────────────┘

          ┌───────────────────────────┐
          │ Burned at a               │
          │ temperature of from       │
          │ 2300° to 2600° F.         │
          └───────────────────────────┘

┌──────────┐    ┌───────────────────────────┐
│ Gypsum   │───▶│ Cooled                    │
└──────────┘    └───────────────────────────┘

          ┌───────────────────────────┐
          │ Pulverized to a fineness  │
          │ of at least 78 %          │
          │ passing the No. 200       │
          │ sieve                     │
          └───────────────────────────┘

          ┌───────────────────────────┐
          │ Portland  Cement          │
          └───────────────────────────┘
```
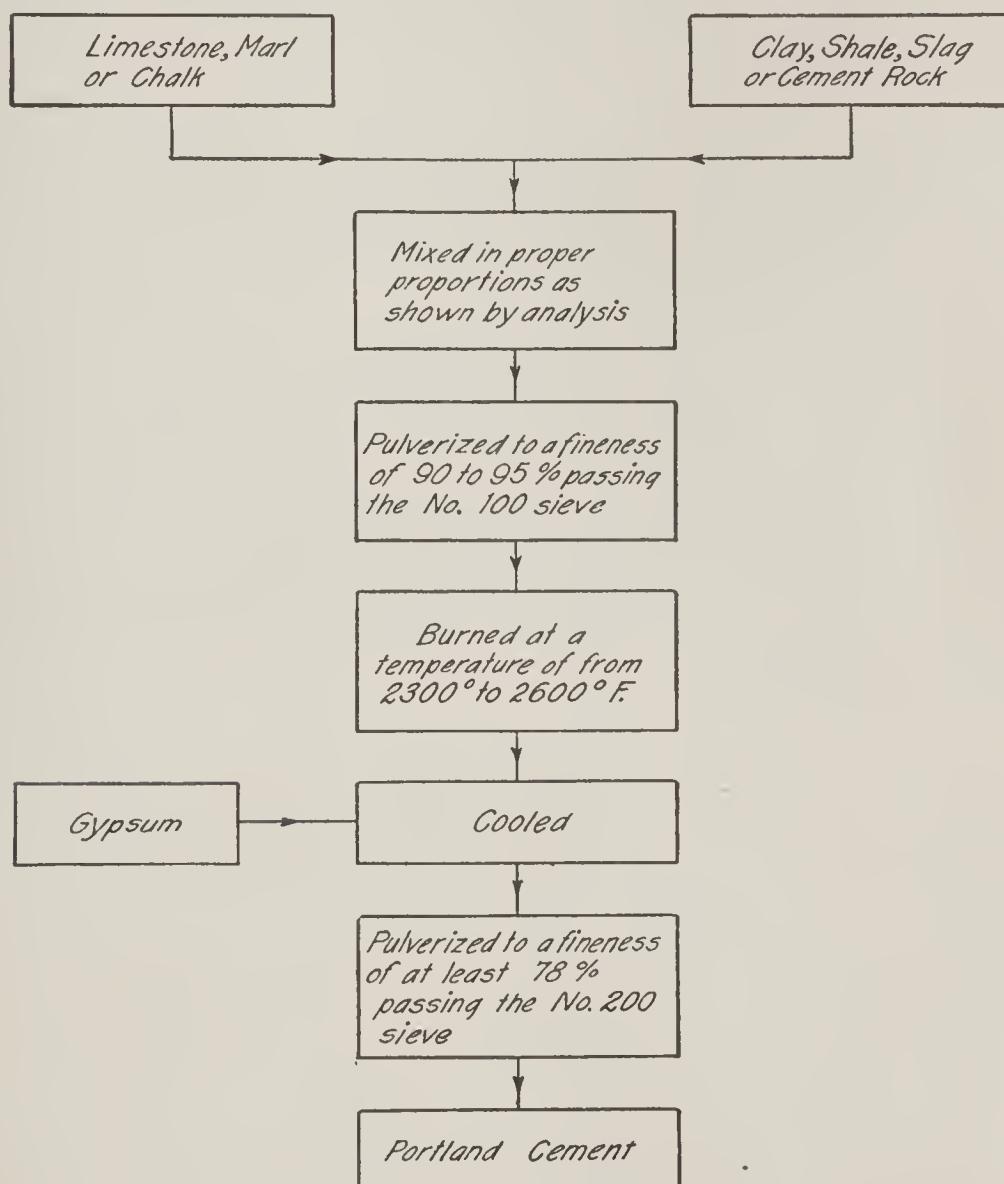
Fig. 10

strength in 28 days. Low-lime cements are likely to be quick-setting. Hence, one of the remedies for quick-setting cement is to increase the quantity of lime in the raw mixture.

The amount of lime that a cement may contain depends on the care with which the mixture of raw materials is made. Thus, poorly ground, imperfectly mixed raw materials would probably result in a very much overlimed cement if the lime

TABLE IX

COMPOSITION OF AMERICAN PORTLAND CEMENTS

Source of Samples	Raw Materials	SiO₂ Per Cent.	Fe₂O₃ Per Cent.	Al₂O₃ Per Cent.	CaO Per Cent.	MgO Per Cent.	SO₃ Per Cent.	Loss Per Cent.
New Jersey....	Cement rock and limestone	21.82	2.51	8.03	62.19	2.71	1.02	1.05
New Jersey....		21.72	2.50	6.62	61.89	3.71	1.22	2.04
Pennsylvania..		22.20	2.27	6.69	62.61	3.00	1.32	1.56
Pennsylvania..		21.94	2.37	6.87	60.25	2.78	1.38	3.55
Pennsylvania..		20.32	2.58	7.30	63.93	2.57	1.27	.83
Michigan.....	Clay and marl	22.71	3.54	6.71	62.18	1.12	1.21	1.58
Michigan.....		21.12	3.59	7.55	63.35	.81	1.59	1.42
Ohio.........		21.41	2.15	6.88	62.72	1.44	1.57	2.18
Ohio.........		21.86	2.45	5.91	63.09	1.16	1.59	2.98
Michigan.....	Clay and alkali waste	22.10	2.35	7.95	61.81	2.15	1.71	1.34
Virginia......	Limestone and clay	21.31	2.81	6.54	63.01	2.71	1.42	2.01
Missouri......		23.12	2.49	6.18	63.47	.88	1.34	1.81
Illinois......	Blast-furnace slag and limestone	22.41	2.51	8.12	62.01	1.68	1.40	1.02

limit as shown by chemical analysis of the clay, marl, limestone, or cement rock of the mixture were almost reached. The coarse particles of calcium carbonate would not come into contact with the silica and alumina sufficiently close to combine with them completely. A properly burned cement will also stand a greater percentage of lime than one which is improperly burned. A cement in which the temperature at burning was too low to heat all the lime to the point of combination with the silica and alumina, would naturally contain free lime. The percentage of lime to be carried at any Portland cement works is usually controlled by two things—the setting time and the soundness. Enough lime must be present to keep the cement from being quick-setting either when made or after seasoning and not so much lime that the cement will fail when tested for soundness. With raw materials high in alumina, the margin between maximum and minimum limits is small. With such materials extreme care is needed in the process of manufacture and the raw materials should be very finely ground and the burning should be thorough. When the amount of alumina is low the margin is much greater, but if the amount of lime is nearly up to the maximum a stronger cement will result.

46. Influence of Silica.—Silica next to lime is the most important constituent of Portland cement. It is present in the proportion of 19 to 25 per cent., cements containing the latter percentage of silica being low in alumina. High-silica cements are usually slow-setting and of good tensile strength. Increasing the amount of silica usually increases both strength and length of setting time. It also increases the temperature of burning. Cement, in order to prevent it from being quick-setting, should contain at least two and one-half times as much silica as alumina.

47. Influence of Alumina.—Portland cement usually contains between 5 and 10 per cent. of alumina. As the percentage of alumina rises the cement sets more quickly, and when the amount of alumina reaches 10 per cent. or more, the cement becomes very quick-setting with a corresponding

decrease of tensile strength. Clinkers obtained on burning mixtures high in alumina are very fusible, hard to burn uniformly, and difficult to grind.

48. Influence of Iron Oxide.—Iron oxide in the cement mixture acts as a flux and promotes the combination of silica and lime. Mixtures of silica, alumina, and lime in the proportions usually found in cement are extremely hard to burn. Iron, however, greatly lowers the temperature of burning. One of the cures for unsound cement is therefore found in the replacement of clays high in alumina by those high in iron. As it does not seem to make cement quick-setting, iron may be made to replace alumina to advantage in many instances. Portland cements containing high percentages of ferric oxide show great resistance to the disintegrating influence of the salts of magnesium, etc., found in sea-water.

Cements high in iron oxide are difficult to grind, as much iron produces a very hard clinker. The color of cement is due to the presence of iron oxide. White Portland cement is made from materials low in iron, such as very pure limestone and white clay, and burned with oil. As a result of this, the resulting cement contains less than .5 per cent. of iron oxide. The clinker is a light green and, when ground, gives a white cement.

49. Influence of Magnesia.—A cement containing $1\frac{1}{2}$ per cent. of magnesia was long considered dangerous; at present, however, 5 per cent. is thought to be harmless and the standard specifications allow this amount in cement. The popular supposition is that in time any considerable amount of magnesia causes cement to expand and crack.

50. Influence of Sulphates.—The effect of calcium sulphate is to delay the setting of cement. For this reason calcium sulphate in the form of gypsum or plaster of Paris is always added to cement after burning. The standard specifications permit manufacturers to add as much as 3 per cent. of calcium sulphate in order to give the cement slow-setting properties. Although the presence of calcium sulphate in small quantities is beneficial to cement, there is no

doubt that more than 4 or 5 per cent. is injurious. The standard specifications allow 2 per cent. of sulphur trioxide, SO_3, in Portland cement.

RAW MATERIALS FOR PORTLAND CEMENT

51. Variety and Source of Raw Materials.—Portland cement is manufactured from a variety of raw materials. Those used may be classed as calcareous or argillaceous, according as the lime or the silica and alumina predominate. The calcareous materials consist of limestone, marl, chalk, and alkali waste; the argillaceous materials consist of clay, shale, slate, and cement rock.

Any combination of materials from these two groups that will give a mixture of the proper composition for burning may be used, but as a rule the combinations used in the United States are as follows:

1. Cement rock and limestone, which is used in the famous Lehigh Valley cement district of Pennsylvania and New Jersey.

2. Marl and clay or shale, which is used principally in Michigan, Ohio, Indiana, and Central New York.

3. Limestone and shale or clay, which is used in many parts of the country, as these materials are widely distributed.

4. Blast-furnace slag and limestone, which is used in plants located in Illinois, Ohio, Minnesota, and Pennsylvania.

5. Caustic-soda waste and clay, which is used by one large plant in Michigan.

52. Cement Rock.—Limestone, to be suitable for cement manufacture, should contain but little carbonate of magnesia, $6\frac{1}{2}$ per cent. being about the limit. It should also be free from quartz either in the form of sand or flint pebbles. Occasionally narrow veins of flint running through the limestone bed will not be harmful because the flint may be sorted out in quarrying. Since the limestone must be reduced to a fine powder in order to mix intimately with the clay or shale used with it, its hardness is an important point in determining its suitability for cement manufacture because fine grinding of the raw materials is essential in order to make a sound cement. The

value of limestone for cement making will be influenced to some extent by the composition of the other material used with it.

The impure clayey limestone used for the manufacture of Portland cement in the Lehigh District is known technically as *cement rock*. This rock forms a narrow belt extending in a northeasterly direction from Reading, Pennsylvania, to a few miles north of Stewartsville, New Jersey. It passes through Berks, Lehigh, and Northampton counties in Pennsylvania, and Warren County in New Jersey, and is about 50 miles long and not over 4 miles at its greatest width. It has been found by experience that a mixture containing about 75 per cent. of calcium carbonate and from 18 to 20 per cent. of clayey matter gives the best Portland cement, and the impure limestones found in the Lehigh Valley approach this composition. When this cement rock contains less than 75 per cent. of calcium carbonate, it is necessary to add a sufficient amount of pure limestone to make up the deficiency. When the rock contains more than 75 per cent. of calcium carbonate, it is necessary to add a little slate or clay. Cement rock is much softer than the pure limestones and consequently is much more easily ground. The nearer it approaches the required composition for cement mixture, the more valuable it is. Rock requiring a small admixture of clay will prove more economical than one requiring the addition of limestone since the cement rock is usually overlaid by clay that has to be removed in order to get at the rock.

At several mills in the Lehigh district neither clay nor limestone is needed and the composition of the cement is controlled by mixing rock high in lime from one part of the quarry with rock low in lime from another part.

53. Marl.—Marl is more or less pure calcium carbonate, the principal impurities being clay, organic matter, and carbonate of magnesia. Marl beds usually occupy the beds of lakes, either present or extinct, and are formed by the precipitation of calcium carbonate from the water by the agency of certain algæ, or water plants. Marl is soft and powdery,

the larger part of it passing a 200-mesh cement-testing sieve. It therefore requires little grinding before burning. White marls are usually free from organic matter, but the gray marls often contain from 5 to 10 per cent. of impurities. Marl beds vary in size from a few acres up to two or three hundred. A cubic foot of marl generally contains about 47.5 pounds of marl and 48 pounds of water. Marls for use in Portland cement manufacture should be free from sand and pebbles. Some marls contain a considerable percentage of sulphur. Just how much sulphur is allowable is hard to say, but at least 5 or 6 per cent. of SO_3 might be present without rendering the marl unfit for the manufacture of Portland cement. The value of a marl bed will usually lie in its depth, area, and physical characteristics rather than in its chemical composition. The greater the depth of the bed, the more economically it can be worked. If the beds are dry so that the dry process of manufacture can be employed, the value of the deposit is greatly increased thereby. Chemically the marl should contain at least 75 per cent. of calcium carbonate and not over 6½ per cent. of magnesia. It should also be practically free from coarse quartz sand.

54. Clay.—Clay consists of a mixture of kaolin with more or less sand and other impurities. Kaolin, or kaolinite, is a hydrated silicate of alumina having the formula $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$. Sand is composed of grains of quartz and other minerals. Clay used for Portland cement manufacture should contain at least two and three-tenths times as much silica as alumina. Iron may replace alumina in almost any quantity without injuring the cement. Magnesia and lime are usually present only in small quantities, the more of the latter present the better, but the amount of magnesia should not be over 3 or 4 per cent. The amount of alkalies present should not run over 3 per cent., as an excess is likely to cause unsound and quick-setting cement. All clay contains some uncombined silica in the shape of quartz sand or pebbles. The sand must be present in the clay in a very finely divided condition. If much more than 5 per cent. is present in the form of grains

that will not pass a 100-mesh sieve, the clay is not suited for cement purposes.

55. Shale.—For cement-making purposes shale may be looked on as solidified clay, the chemical composition of clay and shale being very similar. For mixing with limestone shale is preferable to clay because segregation of the two is less likely to take place. Shale also carries less water and consequently does not require so much drying before grinding. Clays are better suited to mixing with marls because of the similarity of their physical properties.

56. Slag.—Slag suited to the manufacture of Portland cement can come only from iron furnaces working on pure ores such as those of the Lake Superior mines and fluxed with low magnesian limestone. Generally speaking, the slag must have a composition within the following limits: Silica and alumina, not over 48 per cent.; iron and alumina, 12 to 14 per cent.; magnesia, under 3 per cent.

57. Composition of Materials.—Table X shows the composition of various materials used for the manufacture of Portland cement.

58. Valuation of Raw Materials for Portland Cement.—In passing on the availability of raw material, a number of things besides the results of analysis must be considered. The cost of quarrying or excavating, the power required to grind the material, and the coal required to burn it must be taken into account. Marl and clay are the raw materials easiest to excavate, but on the other hand the cement-making plant can seldom be located near the beds of the former, owing to the necessity of having the mill on firm dry ground. In some instances this requirement necessitates pumping or carrying the marl several miles, which increases the cost of manufacture. A very shallow marl bed cannot be worked so economically as a deep one because of the constant moving about of the excavating apparatus, etc. When the marl beds are located in the North cold weather is likely to tie the beds up by the freezing of the lake over them, necessitating

TABLE X—COMPOSITION OF RAW MATERIALS USED IN THE MANUFACTURE OF PORTLAND CEMENT

Kind of Material	Source of Samples	Silica, SiO_2 Per Cent.	Alumina, Al_2O_3 Per Cent.	Iron Oxide, Fe_2O_3 Per Cent.	Lime, CaO Per Cent.	Magnesia, MgO Per Cent.	Sulphur Trioxide, SO_3 Per Cent.	Carbon Dioxide and Water, CO_2+H_2O Per Cent.
Limestone	Iola, Kansas	1.19	.95	1.28	53.13	1.36	trace	42.66
Limestone	Smith's Landing, New York	1.54	.36	1.04	53.87	.52		42.98
Limestone	Suisun, California	1.21	.70	.50	53.62	.44	.11	43.40
Limestone	Bedford, Indiana	.89	.38	.25	54.48	.36		43.40
Limestone	Rockmart, Georgia	2.12	.28	.50	54.06	.77		42.34
Cement rock	Nazareth, Pennsylvania	11.10	4.42	1.24	43.46	1.96	.99	37.10
Cement rock	Siegfried, Pennsylvania	17.32	7.07	2.04	38.59	2.05		32.55
Cement rock	Alpha, New Jersey	15.05	9.02	1.27	39.26	1.90		32.90
Marl	Sandusky, Ohio	1.74	.90	.28	49.84	1.75	1.12	46.01
Marl	Newago, Michigan	.72	.24	.12	55.12	.44	trace	43.77
Marl	Warners, New York	.26	.21	.01	50.98	.19		40.26
Marl	Coldwater, Michigan	1.19	.55	.25	52.50	1.16	1.84	42.51
Clay	Stroh, Indiana	56.74	19.43	4.83	7.27	3.05		10.39
Clay	Wayland, New York	45.21	19.08	6.74	11.17	1.57	1.55	14.64
Clay	Warners, New York	42.85	13.51	4.49	12.69	3.32	2.85	13.57
Shale	Yankton, South Dakota	57.98	18.26	4.57	1.75	1.83	1.28	12.08
Shale	Alpena, Michigan	61.15	18.47	5.05	.98	2.26	.91	7.02
Slag	Chicago, Illinois	33.10	12.60 (combined)		49.98	2.45		
Alkali waste	Wyandotte, Michigan	.60	3.04 (combined)		53.33	.47		

either the cutting of the ice or the shutting down of the mill, either one or both of which contingencies add to the cost of production. Cement rock is usually blasted down, loaded on cars, and hauled by cable to the mill, which is usually close at hand. Cement rock costs more than marl in explosives and drilling, but if a steam shovel is used to load the cars it costs less to convey to the mill after it is down, as only half as much material has to be handled owing to the water in the marl. Limestone is harder than cement rock and costs more to drill and blast; it also costs more to break up the lumps into sizes suitable for loading on the cars or carts. The cost of quarrying and loading shale will be about the same as in the case of cement rock. The cost of getting out either cement rock or limestone will be influenced by the amount of stripping, or removal of soil above the deposit, that has to be done. In some mills this top material can be used, in which case the cost of removal is saved.

59.   Marl and clay are the easiest materials to grind; shale, cement rock, and chalky limestone come next, while limestone and slag are harder still. Cement-rock limestone mixtures burn the easiest of any of the combinations in the kilns, limestone-clay and slag-limestone mixtures are harder still, and the wet marl and clay mixtures require much more coal than any of the others.

The mere fact that raw materials of suitable chemical composition for the manufacture of Portland cement exist in a certain locality is no reason why a mill should be erected on the site, because the success of the enterprise will depend more on local conditions than on raw materials themselves. The cost of fuel, labor, and supplies, as well as ability to market the product, must be taken into consideration. The fuel item in the manufacture of Portland cement is a big one, dry material requiring from 165 to 200 pounds of fuel per barrel of cement, and wet material from 200 to 250 pounds under the usual system for burning and grinding. Portland cement is so bulky in proportion to its value that the nearness of the mill to the market is also an important item.

CALCULATING PORTLAND-CEMENT MIXTURES

60. In spite of considerable research, the composition of Portland-cement clinker is by no means thoroughly understood. The best opinions, however, seem to agree that there are certainly two essential compounds in ideal clinker. These compounds are tricalcium silicate, $3CaO \cdot SiO_2$, and tricalcium aluminate, $3CaO \cdot Al_2O_3$. A less desirable compound always present in cement is the dicalcium silicate, $2CaO \cdot SiO_2$. The tricalcium silicate is, of course, more basic and contains 50 per cent. more lime than the dicalcium silicate. Unquestionably, the nearer cement comes to being composed of only tricalcium silicate and tricalcium aluminate, the better it is. This is another way of saying that so long as it is in combination with the silica and alumina, the more lime that cement contains the better it is. The tricalcium aluminate has the following composition :*

Alumina, $Al_2O_3 = (27 \times 2) + (16 \times 3) = 54 + 48 = 102$
Lime . . . . $3CaO = (40 + 16)3 = 168$

Hence, there is present $\frac{168}{102} = 1.65$ times as much lime as alumina. Similarly the tricalcium silicate contains 2.8 times as much lime as silica. Now, in order to form tricalcium aluminate there must be present 1.65 pounds of lime for every pound of alumina in the cement mixture; similarly, for every pound of silica there must be 2.8 pounds of lime. Thus, 2.8 pounds of lime is equivalent to 5 pounds of calcium carbonate $(CaCO_3 : CaO = 5 : 2.8$, or $100 : 56 = 5 : 2.8)$ and 1.65 pounds of lime is equivalent to 2.95 pounds of calcium carbonate $(100 : 56 = 2.95 : 1.65)$.

To express these relations in the shape of formulas, let

x = percentage of calcium carbonate in any cement mixture;
a = percentage of silica;
b = percentage of alumina;
y = percentage of lime.

Then,
$$x = 5a + 2.95\,b \qquad (1)$$
$$y = 2.8\,a + 1.65\,b \qquad (2)$$

*For convenience in calculation, the atomic weights are taken as follows: $Ca = 40$, $O = 16$, $Al = 27$, $C = 12$, and $Si = 28$.

These formulas give the maximum amount of lime that a cement could carry if it were manufactured under ideal conditions of grinding and burning. Under the conditions met in actual practice, however, it is not possible to grind the raw material fine enough to allow all the lime to combine with the silica and alumina; and, since an excess of clay is less harmful than an excess of lime, it is customary to allow a slight margin between the lime actually present in the mixture and the theoretical lime requirements. It has been found in practice that from 90 to 92 per cent. of the lime required by the formula is all that can be safely used. Taking 90 per cent. as the maximum, formula **1** becomes

$$x = 4.5\,a + 2.7\,b \qquad (3)$$

61. In order to show the method of using the formula, let it be required to make a cement mixture from limestone and cement rock of the following compositions:

	CEMENT ROCK	LIMESTONE
Silica	19.06	2.14
Iron oxide	1.14	.46
Alumina	4.44	1.00
Calcium carbonate	69.24	94.35
Magnesia	4.21	2.18

The calculation of the mixture is as follows:

LIMESTONE

Total calcium carbonate 94.35
$CaCO_3$ needed for the silica present $2.14 \times 4.5 = 9.63$
$CaCO_3$ needed for the alumina present $1.00 \times 2.7 = 2.70$ 12.33

Available calcium carbonate 82.02

CEMENT ROCK

$CaCO_3$ needed for the silica . . . . . $19.06 \times 4.5 = 85.77$
$CaCO_3$ needed for the alumina . . . $4.44 \times 2.7 = 11.99$ 97.76

Less calcium carbonate contained 69.24

Required calcium carbonate for 100 parts . .   28.52

The number of pounds of limestone required for 100 pounds of cement rock will then be

$$\frac{28.52 \times 100}{82.02} = 35, \text{ nearly}$$

Now 35 pounds of limestone contains
$$\ldots\ldots\ldots.35\times94.35=\ 33.02 \text{ pounds } CaCO_3$$
100 pounds of cement rock con-
tains . . . . . $69.24\times100=\ \underline{69.24}$ pounds $CaCO_3$

135 pounds of mixture contains 102.26 pounds $CaCO_3$

The mixture would therefore analyze

$$\frac{102.26\times100}{135}=75.7 \text{ per cent. of calcium carbonate}$$

62.   The whole operation of calculating cement mixtures may be condensed into one formula, as follows:

$$X=\frac{(A\times4.5+B\times2.7)-C}{c-(a\times4.5+b\times2.7)}$$

in which $X=$ percentage of limestone or marl needed per ton
or per pound of cement rock or clay;
$A=$ percentage of SiO_2 in cement rock or clay;
$B=$ percentage of Al_2O_3 in cement rock or clay;
$C=$ percentage of $CaCO_3$ in cement rock or clay;
$a=$ percentage of SiO_2 in limestone or marl;
$b=$ percentage of Al_2O_3 in limestone or marl;
$c=$ percentage of $CaCO_3$ in limestone or marl.

Cement mixtures proportioned by this formula will be neither overlimed nor underlimed, and the resulting cement, if the mixture has been properly ground and burned, will give good results when tested for strength and soundness.

The preceding formula is very useful for calculating cement mixtures from complete analyses, as in making laboratory trial burnings, starting up a new mill, or opening a new deposit. However, it will be found more practicable in actual mill routine work to fix on a certain percentage of calcium carbonate found by experience to give satisfactory results and to keep the mixture as near this percentage as possible. Provided the amount of water, organic matter, and magnesia in the raw materials is constant, it will be comparatively easy to keep a fairly uniform mixture by merely watching the percentage of calcium carbonate.

63.   The mathematical part of calculating cement mixtures for a fixed lime standard may be simplified by the following formulas, the first of which is for use when the cement rock is weighed and the proper proportion of this weight of limestone is added:

To find the percentage of a given limestone to be added to a given cement rock or clay to make a given mixture, let

X = percentage of limestone necessary;
L = percentage of $CaCO_3$ in limestone;
R = percentage of $CaCO_3$ in rock or clay;
M = percentage of $CaCO_3$ desired in the mixture.

Then,
$$\frac{LX + 100R}{100 + X} = M$$

or
$$LX + 100R = 100M + XM$$
$$LX - MX = 100M - 100R$$
$$X(L - M) = (M - R)100$$

$$X = \frac{M - R}{L - M} \times 100 \qquad (1)$$

Also,
$$\frac{X}{100} = \frac{M - R}{L - M} = \frac{\text{limestone}}{\text{cement rock}}$$

Hence,
$$\text{limestone} : \text{cement rock} = (M - R) : (L - M)$$

Example.—What percentage of limestone analyzing 95 per cent. $CaCO_3$ must be added to a cement rock analyzing 70 per cent. $CaCO_3$ to give a mixture analyzing 75 per cent. $CaCo_3$?

Solution.—The percentage of limestone is found by applying formula **1**; thus,
$$X = \frac{75 - 70}{95 - 75} \times 100 = \frac{500}{20} = 25$$

Hence, to every 100 lb. of cement rock 25 lb. of limestone must be added.   Ans.

The second formula is practically the same as the preceding one, but it is intended for use when the limestone or marl is weighed and the proper proportion of this weight of clay or shale is added.

To find the percentage of a given clay or shale (or cement rock) to be added to a given marl or limestone to make a given mixture, let

X = percentage of clay or shale necessary;
C = percentage of CaO in clay or shale;
L = percentage of CaO in marl or limestone;
M = percentage of CaO desired in the mixture.

Then,
$$X = \frac{L - M}{M - C} \times 100 \qquad (2)$$

Also,
$$\frac{X}{100} = \frac{L - M}{M - C} = \frac{\text{limestone}}{\text{clay}}$$

Hence,   limestone : clay $= (L - M) : (M - C)$

EXAMPLE.—What percentage of clay analyzing 2.5 per cent. CaO must be added to a limestone containing 53 per cent. CaO to obtain a mixture analyzing 41.0 per cent. CaO?

SOLUTION.—The percentage of clay is found by applying formula **2**; thus,
$$X = \frac{53 - 41}{41 - 2.5} \times 100 = \frac{1,200}{38.5} = 31. \quad \text{Ans.}$$

Instead of percentages of CaO, percentages of $CaCO_3$ may be used, but, if used in one case, must be used in all.

QUARRYING OF DRY MATERIALS

64. Limestone, cement rock, and shale are usually quarried, while clay is dug from pits and marl is often dredged from lakes and similar bodies of water. Deposits of cement rock and limestone are usually overlaid by a few feet of soil and clay, which must be removed by scrapers or by shoveling. When clay is used to make the mixture, this surface deposit is conveyed to the mill; otherwise it is carted away to a dump. Some deposits of rock and limestone are so situated that they can be opened on a hillside; with others it is sometimes necessary to dig straight down into the earth.

The stone is usually blasted down in benches, sometimes along the whole face of the quarry at once; at other quarries, only a small part of a bench at a time. The drill holes for the blasting are made with power drills operated by steam or compressed air, and these holes are carried to a depth of

16 to 20 feet. In blasting, an effort is made to shatter the rock as much as possible in order to save subsequent sledging and blasting to break up the big pieces to a size that can be easily handled and crushed.

In some quarries the rock is loaded on carts by hand and carried to a point out of danger from the blasting and dumped into side-dump cars which are hauled up an incline to the mill by a cable hoist. At other mills temporary tracks are laid from a turntable or switch at the foot of the incline to the rock piles; the cars are loaded directly from these and then hauled to the mill, as before. When the quarrying has been carried straight down the rock is loaded on skips that are hoisted up and carried to the mill by an aerial cable.

Rock can be loaded much more cheaply with steam shovels than by hand and these are now used much in cement-mill quarries. To be successfully used, however, they require the installation of large crushers in the mill in order to crush the large stone which the steam shovel loads.

65. Excavating of Marl.—Marl carries considerable water and the deposits usually lie in depressions and underneath the surface of a shallow lake or marsh. In excavating marl several plans are followed. One of the most common is to use a steam dredge mounted on a barge. The dredge scrapes up the marl from the bottom of the lake and loads it on barges. The barges are then towed to a wharf and unloaded by machinery, belt conveyers being used to carry the marl to the mill. Instead of using barges and cars for this purpose, the marl is sometimes dropped from the scoop of the dredge into the hopper of a pug mill on a boat or car. Here the marl is mixed with water to form a thin mud which is pumped to the mill through a pipe line carried over the marsh or marl bed on a wooden trestle. The dredges are of the same type as those used for deepening the channels of rivers and harbors. They consist of a scoop or dipper having a hinged bottom and fixed to a long arm. This arm can be swung to either side, raised, lowered, or pushed forward by a system of chains, racks, and pinions. The pug mill consists of a long

steel cylinder in which two shafts provided with steel blades revolve. The marl and water are fed in at one end and forced out at the other. During their passage they are churned up by the blades and thoroughly mixed.

MIXING PROCESSES

66. Mixing the Raw Materials.—In mills using the dry process the rock goes from the quarry to a stone house. Here it is treated in one of four ways:

1. It is dumped directly into large piles and later subjected to analysis to determine how much limestone or clay must be added. After being weighed the rock is loaded on buggies, or barrows, and wheeled to the crusher where it meets another buggy, or barrow, loaded with the calculated amount of limestone or clay. The contents of the two barrows are then dumped into the crusher together or separately.

2. The rock is weighed as it comes from the quarry and the proper amount of limestone or clay, as calculated from quarry analyses, is added. The contents of part of the cars are then dumped into the crusher and the contents of the other cars are dumped into a pile from which when necessary the material is wheeled to the crusher in barrows, etc. At several mills the contents of all the cars are dumped into the crusher, part of the crushed stone going to the mill and part of it being stored in bins for the night shift. The rock is drawn from the bins on belt conveyers running to the mill.

3. The materials are crushed separately and stored in large bins the contents of which are analyzed. The materials are then mixed in proper proportions as determined by these analyses. This plan is followed at most of the plants using limestone and clay or shale.

4. The materials are ground to a fineness of, say, from 10 to 18 mesh, stored in separate bins of a capacity sufficient for 6 hours or more, then analyzed and mixed accordingly. This is a particularly desirable way in the case of a clay-and-limestone mixture. The raw materials are weighed and then mixed during the grinding operation.

67. At some time during the mixing process the rock is usually dried. This is done in rotary driers, Fig. 11, consist-
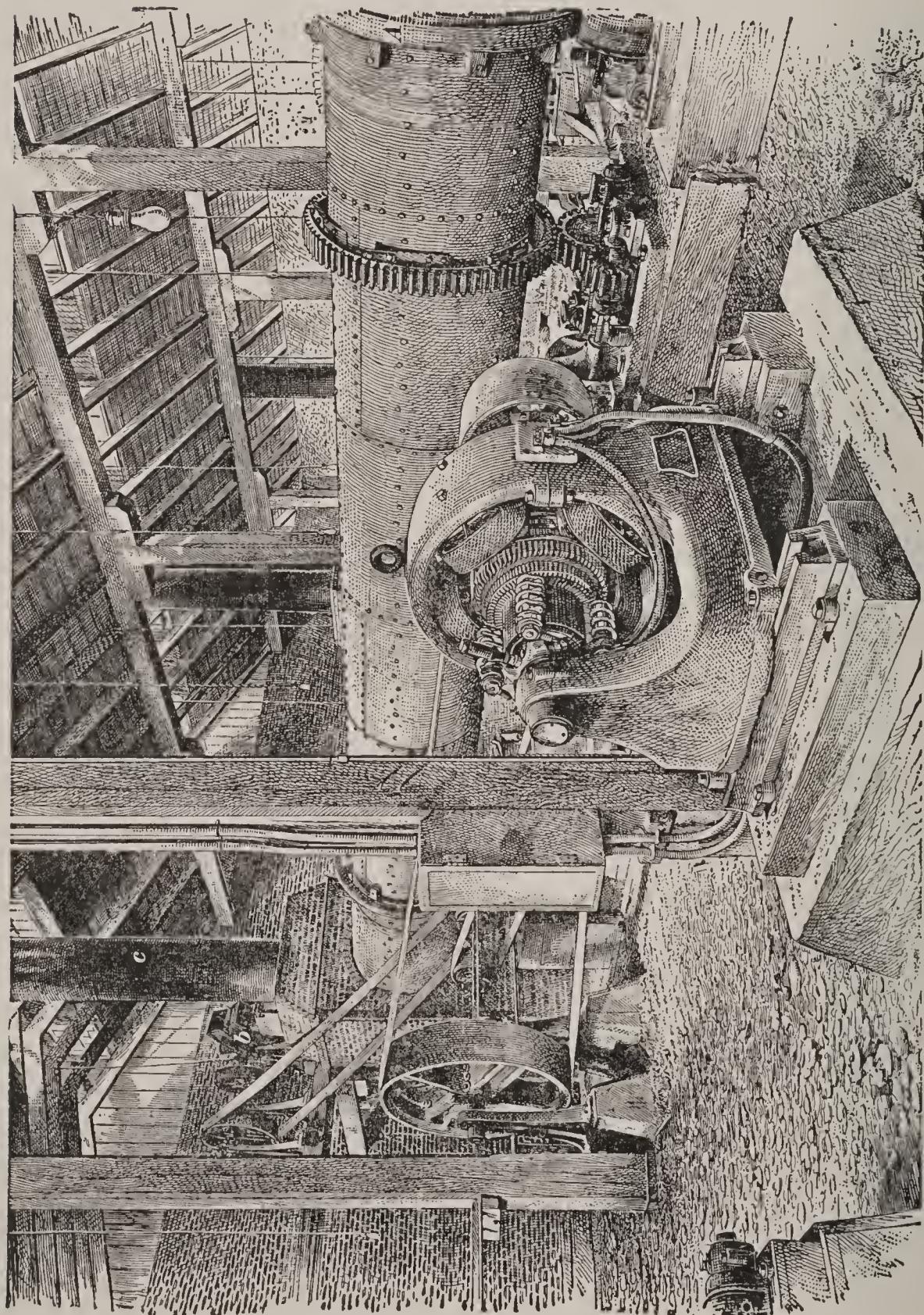

Fig. 11

ing of steel cylinders generally 50 feet long and 5 feet in diameter. These driers are usually provided with angle irons bolted to the inside to act as shelves to carry the rock up and

expose it to the hot gases. Some of the cylinders have their upper half divided by means of plates into four compartments in order to expose a greater surface of rock. The driers are heated by a coal fire at the lower end. They are similar in construction to the rotary kiln previously described, except that they are not lined with firebrick. One drier 50 ft.×5 ft. will take care of 400 to 500 tons of rock in 24 hours.

68. In the wet process the marl is usually received at the mill in the form of a thin mud. After removing roots, sticks, stones, etc., this mud is stored in large concrete basins or in steel tanks. The clay is dried, ground, and stored in bins. From the storage tank the marl is pumped either into a tank of known volume or into the hopper of a scale. The clay is then added as directed by the chemist. From the measuring tank or scales the mixture, or *slurry,* as it is called, is dumped into a pug mill and thoroughly mixed. From the pug mill the mass is run into large vats where it is sampled and analyzed. If of correct composition it is passed on for final grinding; if not, the required quantity of marl or of clay, as the case may be, is added. The vats are provided with stirrers to keep the mass in constant agitation to prevent the settling of any part of it and to mix in thoroughly any clay or marl that may be added to correct the mixture. Compressed air is used for agitating the contents of the slurry tanks and also revolving arms provided with paddles. In calculating the amount of clay for marl or slurry, it is always necessary to find the percentage of water in the slurry and from this the amount of dry material in the vat. The amount of clay needed for this amount of dry slurry or marl is then calculated and added in the manner already explained in detail.

Cement is also made from limestone and clay or shale by the wet process. In this ‘process the limestone and shale are handled as just described, and water is added just before the mixed materials are ground. If clay is employed in place of shale, it is usually mixed with water and reduced in a wash mill to a thin slip which is added to the limestone just before the latter is ground. It is claimed for the wet process when

applied to limestone and clay or shale that the grinding of the two materials is easier than in the dry process, and the drying operation is omitted.   On the other hand, much more coal must be burned in the wet process than in the dry.

GRINDING

69.   Grinding the Raw Material.—Before burning it is necessary to grind the mixture of raw materials to a fine powder.   Dry materials are usually ground in three stages (*a, b,* and *c*).

(*a*)   The first stage always consists in crushing the limestone or cement rock down to pieces 2 or 3 inches in size. This operation itself is usually done in two stages.   A large crusher is employed to break the stone as received from the quarry, often in pieces a yard or more in size, down to about 6 inches.   This large crusher is then followed by smaller gyratory crushers or large hammer mills which reduce the stone to 3 inches and under, the size depending on the machinery employed in stage (*b*).*

(*b*)   In this stage the material is reduced sufficiently to pass it on to the third stage (*c*).   When tube mills are used for finishing the grinding it is necessary to reduce the material to 20-mesh, but where Raymond mills, Griffin mills, or Fuller mills are employed for finishing it is necessary to reduce to only about 1 inch.   In the latter event rolls or hammer mills are used in this stage.   When the final grinding is done by means of tube mills the second stage grinding may be done by: (1) ball mills; (2) kominuters; (3) hammer mills; (4) Bradley Hercules; or (5) Griffin mills.

(*c*)   The final grinding may be done in: (1) Tube mills; (2) Griffin mills; (3) Fuller mills; and (4) Raymond mills. A combination ball and tube mill called a *compeb* mill is now employed to some extent and combines stages *b* and *c* in one operation.   In the wet process as applied to limestone and

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*Note.—The stone is usually dried after it passes through this crusher, and goes into storage.   In the case of a limestone and clay plant, the mixing is often done while the rock is in this condition.

clay, or shale, the grinding is usually done in ball mills or kominuters followed by tube mills, or else by compeb mills alone.   No drying is necessary.

Opinions differ greatly as to what combinations are most efficient.   Some manufacturers prefer one and some another, and there are good points in all.   Unquestionably, too, some combinations give better results in certain hands or on certain materials, etc., than do others.

Wet materals—marl and clay—are in a more or less finely ground state when excavated and the grinding here becomes more of a mixing process.   The clay is usually disintegrated in dry pans or edge-runner mills, and the mixture of clay and marl is merely passed through a tube mill and then burned.   These mills are described in detail later.

70.   The degree of fineness to which the raw material should be ground depends largely on conditions.   It may be said that as a general rule the raw material should never be ground coarser than will permit 90 per cent. of the material to pass through a 100-mesh sieve and that in most cases a fineness such that 95 to 98 per cent. will pass through the sieve is required to produce a sound cement.   Fine grinding also lessens the quantity of coal required for burning.   The fineness of the raw material should be tested at least once a day and, if possible, two or three times a day, in order to have a check on the work of the mills and to keep them up to standard.

71.   Crushers.—The crushers used in cement works are usually of the gyratory type, though the jaw or Blake crusher is used to some extent.   Fig. 12 shows a section of a Gates gyratory crusher.   On the spindle g is mounted a chilled-iron crushing head c.   The hopper-shaped top shell h is lined with concave chilled plates.   The crushing is done in the annular space between the chilled surfaces of the crushing head and liners.   The spindle is held centrally in the spider at the top and at the bottom it passes loosely through an eccentric driven by bevel gears b to give the spindle a gyrating motion.   Thus, one point in the annular space is wide, while a point opposite
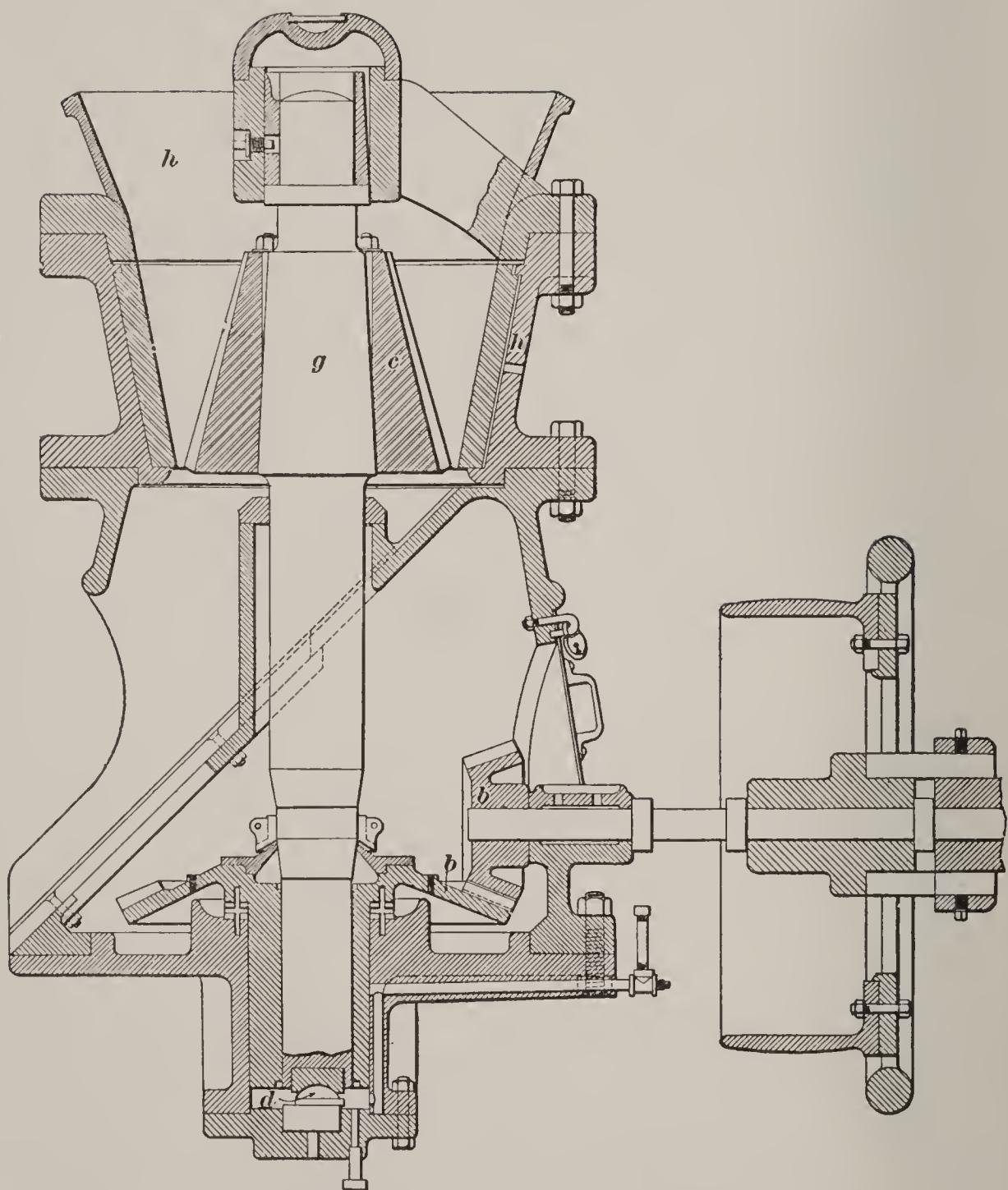
FIG. 12

is narrow, and the crushing force is obtained on account of the head approaching and receding from the concave liners. Crushers of this type are made in a variety of sizes and require from 1 to 1.2 horsepower per ton of rock crushed per hour, depending on the hardness of the rock.

72.   Large jaw crushers are now used to some extent for breaking down the rock as it comes from the quarry.   These have the advantage that they will take a larger piece of rock than will a gyratory of the same capacity and hence are desirable where steam shovels are used in the quarry and it is desired to keep the cost of the crushing plant low.   Jaw
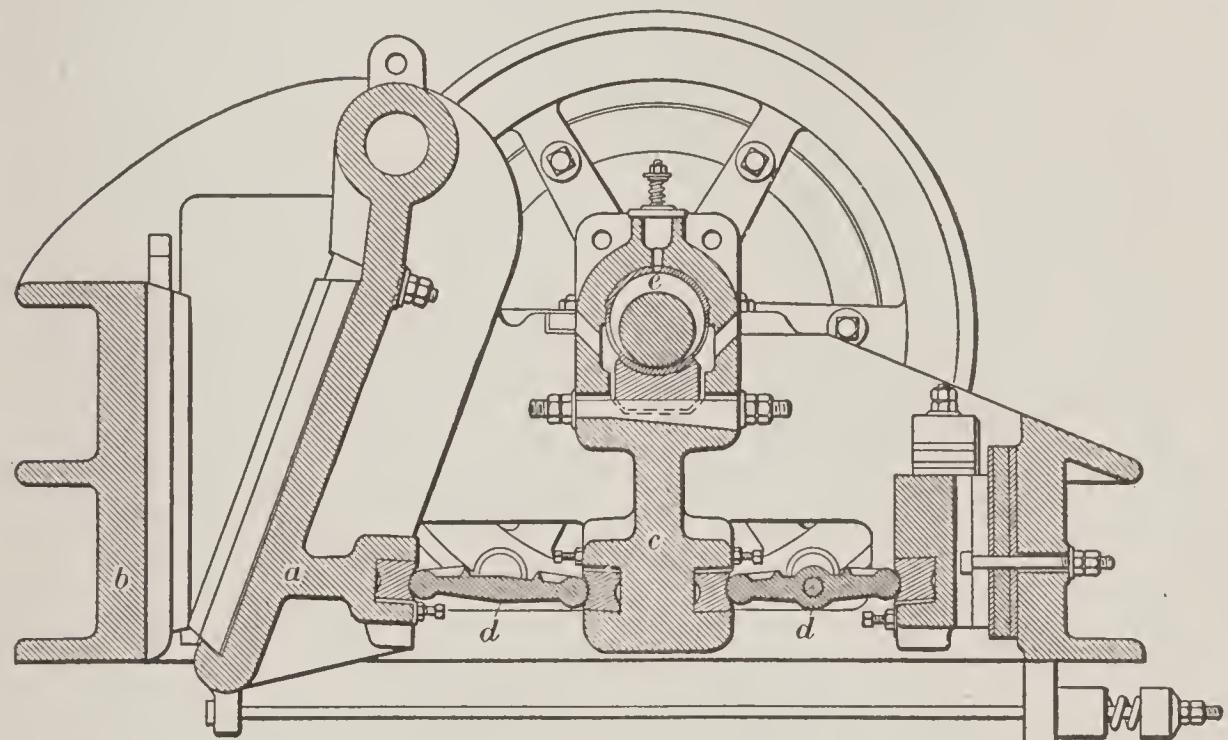

Fig. 13

crushers do not have as great capacity as the gyratory crushers, however, and are more easily clogged by means of clay in the rock.   The jaw crusher, Fig. 13, as its name implies, consists of a swinging jaw *a*, which alternately approaches and recedes from a stationary jaw *b* fixed to the frame of the machine.   The movement of the jaw is brought about by means of what is known as a *pitman c*, two toggles *d*, and an eccentric *e*.   It will be readily seen from a reference to Fig. 13 that as the eccentric raises the pitman the toggles straighten out and force the movable jaw nearer the fixed one, etc.   The size of jaw crushers usually employed in cement mills have

openings 60 in.×48 in. and 84 in.×60 in. They require the same power to operate as a gyratory crusher.

73. Griffin Mill.—The Griffin mill, which is shown in Fig. 14, though more complicated and consisting of a greater
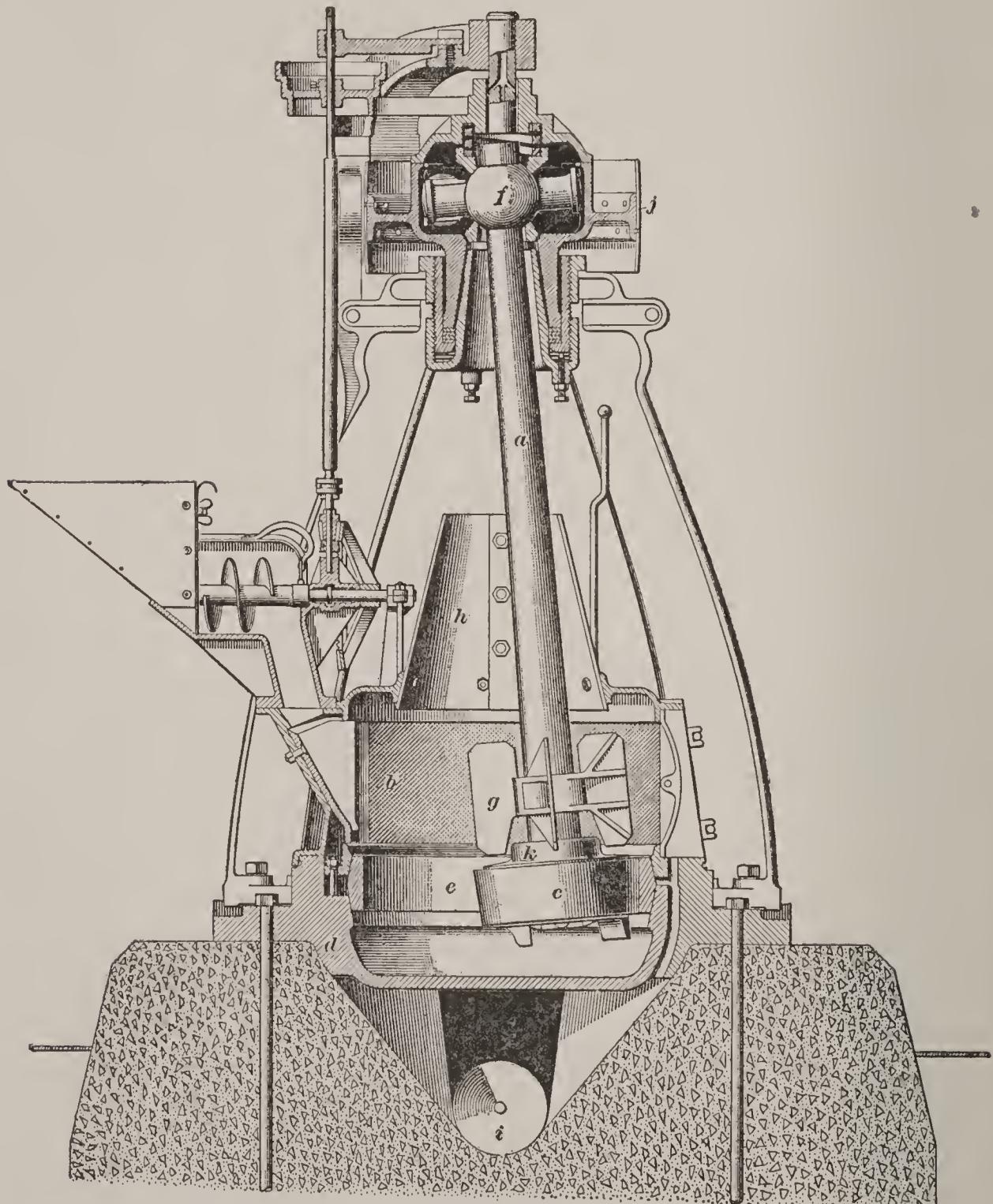

Fig. 14

number of parts than either ball or tube mills, is admirably adapted to grinding or pulverizing both raw stone and clinker. It consists of a shaft a vertically suspended by a universal joint

composed of a ball f with attached trunnions. The trunnions work in half boxes that slide up and down in recesses in the pulley-head casting. The shaft is driven by the pulley j. At the bottom of the shaft will be seen a fan g that draws in air from the top of the cone h and throws finely pulverized material against the vertical screen b on its own level. Below this fan is a roll c. The body of the mill consists of a base, or pan, d, against which the roll revolves, coming in contact with the steel ring, or die, e. It is between these parts that the material is pulverized, the finer particles being driven through the screen and the coarser ones falling to the bottom of the pan, only to be stirred up again by the plows, or scoops, on the bottom of the roll and brought between the die and roll. Outside of the die the base has a number of openings through which the pulverized material is led downwards to the screw conveyer i underneath. The screen that surrounds the pulverizing chamber is of much coarser mesh than the delivered product; for instance, a 16-mesh screen delivers a product of which more than 90 per cent. will pass a 100-mesh screen.

A Griffin mill of the size usually installed in Portland cement works will grind from 4 to 6 tons of rock or from 12 to 15 barrels of cement per hour, the amount varying with the hardness of the rock and the condition in which the mill is kept. In doing this work from 75 to 80 horsepower will be consumed.

74. The Bradley Hercules Mill.—The Bradley Hercules mill is a new mill developed by the makers of the Griffin mill. It is somewhat similar to the latter in principle. This mill has three rolls, however, instead of one and is much larger than the Griffin mill. The rolls are suspended by a suitable frame and bearings from a single central shaft to which is attached the driving pulley. The mill is provided with screens and fans which perform the same work as in the Griffin mill. These mills are used only as preliminary mills to tube mills, as they will take 2- to 3-inch material and reduce it to 20-mesh. They have a very large capacity. One mill under these conditions will grind 100–150 barrels of clinker,

or 30 to 40 tons of raw material per hour and requires 200–250 horsepower.

75. Ball Mills.—Figs. 15 and 16 show two views of a ball mill that consists of a steel drum about 8 feet in diameter
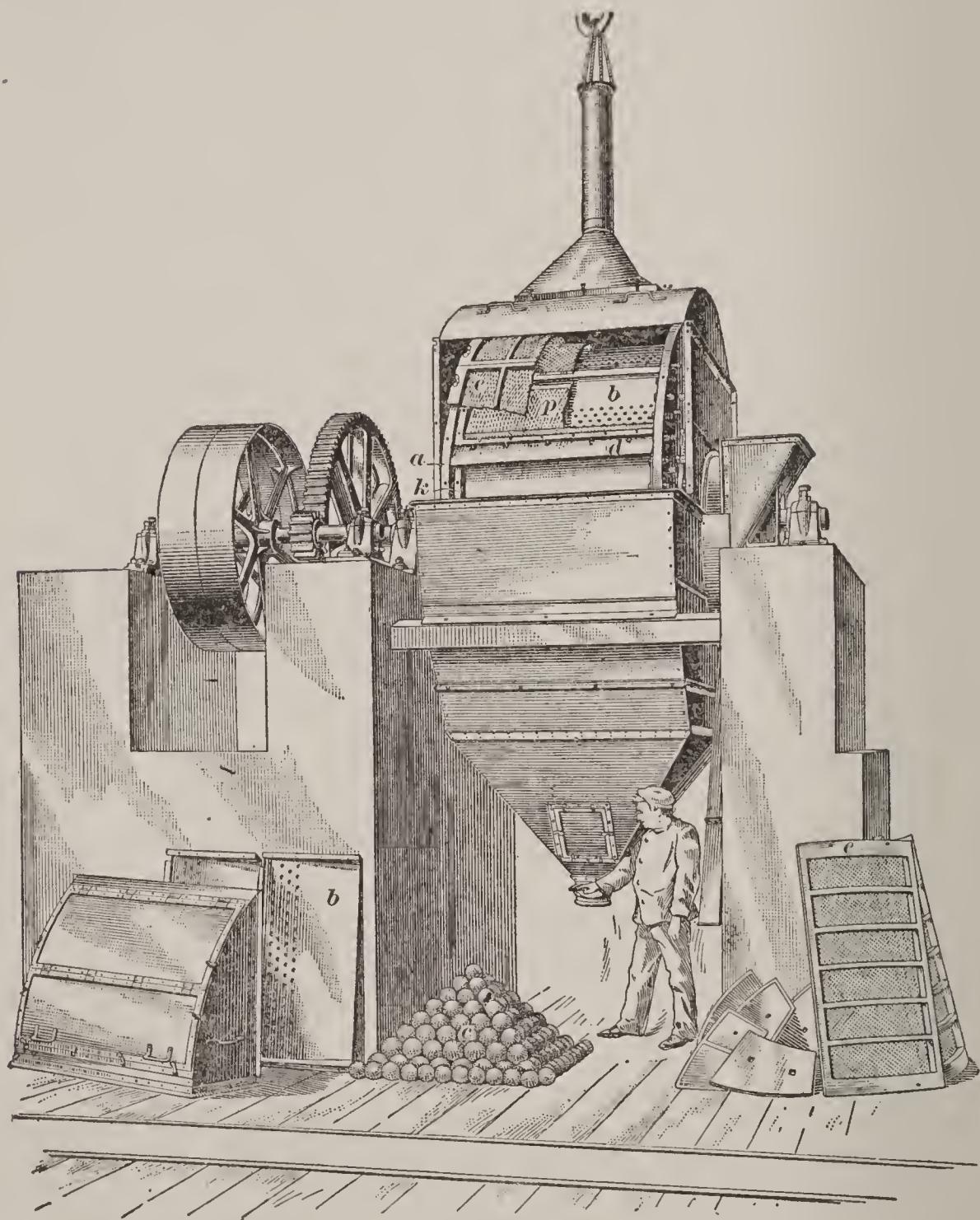

Fig. 15

and 4 feet wide, the inner surfaces of which are lined with heavy plates of tough, hard steel. The drum revolves on a central shaft and carries with it part way round a number of steel balls *c* that by means of a series of offsets, or steps, *h* in

the grinding plates are made to roll or fall on the material to be crushed. At each of the offsets is a slot, or opening, for the return of material to the mill. The grinding plates *b* are perforated, and the balls grind, or force, material through to the outside where it works its way to a series of screens *e* and *p* that separate the fine particles by allowing them to pass to the outer casing and drop to the hopper below while the coarser particles are returned to the mill through slots, or return channels, by scoop plates *d* for further reduction. The fineness of the grinding is regulated by the outer screen *e*, which is usually from 12 to 20 meshes per linear inch. This screen is attached to the rim *a* by setscrews. The coarser and inner screen *p* is made of perforated metal plates and is bolted to the rim *k*.

A ball mill usually requires from 30 to 40 horsepower and turns out 4 to 6 tons of raw material and 12 to 16 barrels of clinker per hour. The balls vary from 3 to 5 inches in diameter, and the

FIG. 16

charge of balls for a mill of the above size weighs about 1½ tons.

A modification of the ball mill in which no screens or perforated plates are used, consists of a short tube mill lined with corrugated chilled iron plates and charged with large steel balls. The material is fed in through a hollow shaft at one end and works its way out through one at the other. The fineness, as in tube-mill grinding, is regulated by the feed. A few cement plants have these ball mills.
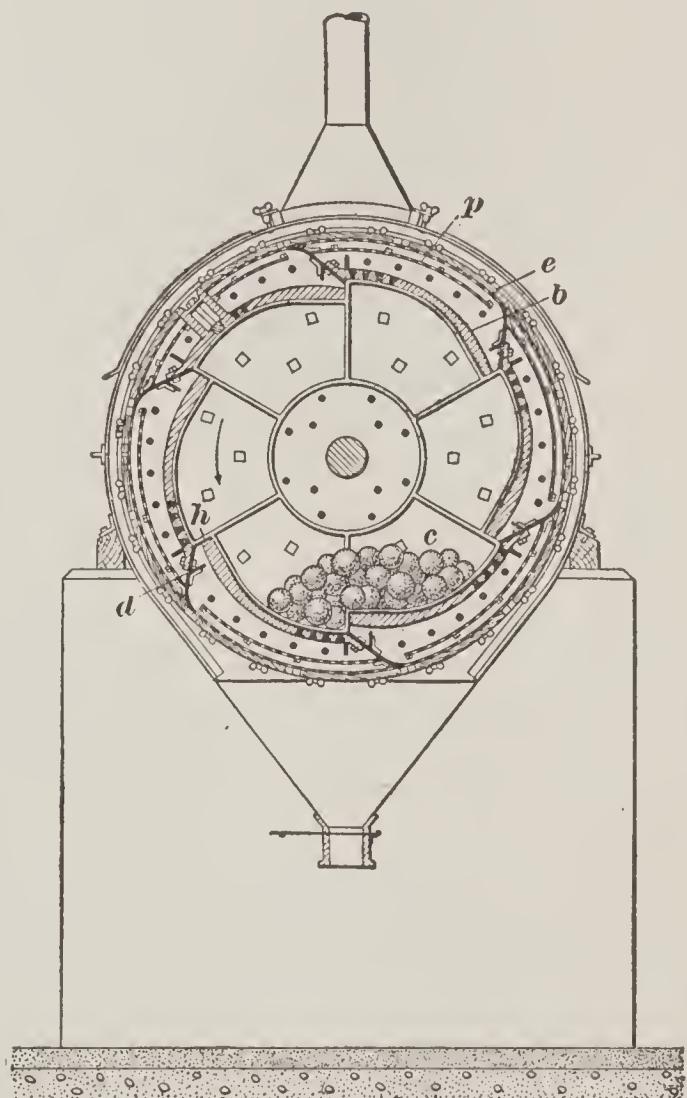
76. Kominuter.—A modification of the ball mill having about double the capacity of that shown in Fig. 16, is known as the *kominuter*. It consists of a drum of nearly the same diameter as a ball mill, but of about twice its length. In action it differs from the ball mill chiefly in that the grinding plates are not perforated. Therefore the material does not fall out through the screens at once, but travels through the full length of the drum and passes on to a perforated plate screen through openings at the opposite end. The particles that are too large to pass through this screen are returned automatically to the interior of the mill by means of buckets and **S**-shaped pipes. The material passing the inside screen is caught on the outside screen of wire cloth and further separation effected, the coarse material being returned to the mill as before.

77. Tube Mill.—The tube mill shown in Fig. 17 consists of a cylinder of boiler plate, usually 5 to 7 feet in diameter and 20 to 22 feet long, suspended on trunnions, or bearings, at either end and rotating about a horizontal axis. The cylinder is lined with flint or trap-rock blocks cemented in, or with tough cast steel or other metal plates, and is filled to about half its capacity with hard Greenland or Danish flint pebbles varying from 1 to 3 inches in diameter. By a screw conveyer arrangement at one end material is fed in and discharged at points lying in either the axis or the perimeter of the cylinder. The material to be pulverized is fed in at one end and works its way toward the other while the mill is kept constantly rotating at a rate of 25 to 28 revolutions per minute. The tumbling of the pebbles on one another, with the material to be ground forming the bed in which they roll, causes the fine pulverizing action of the mill. The fineness is regulated by a device at the feed-end of the mill. This device can be set to control the amount of material entering and this in turn regulates the speed of material passing through and, consequently, the resulting fineness. By using this mill, a material of which 98 per cent. will pass a 100-mesh screen can easily be obtained.

Fig. 17
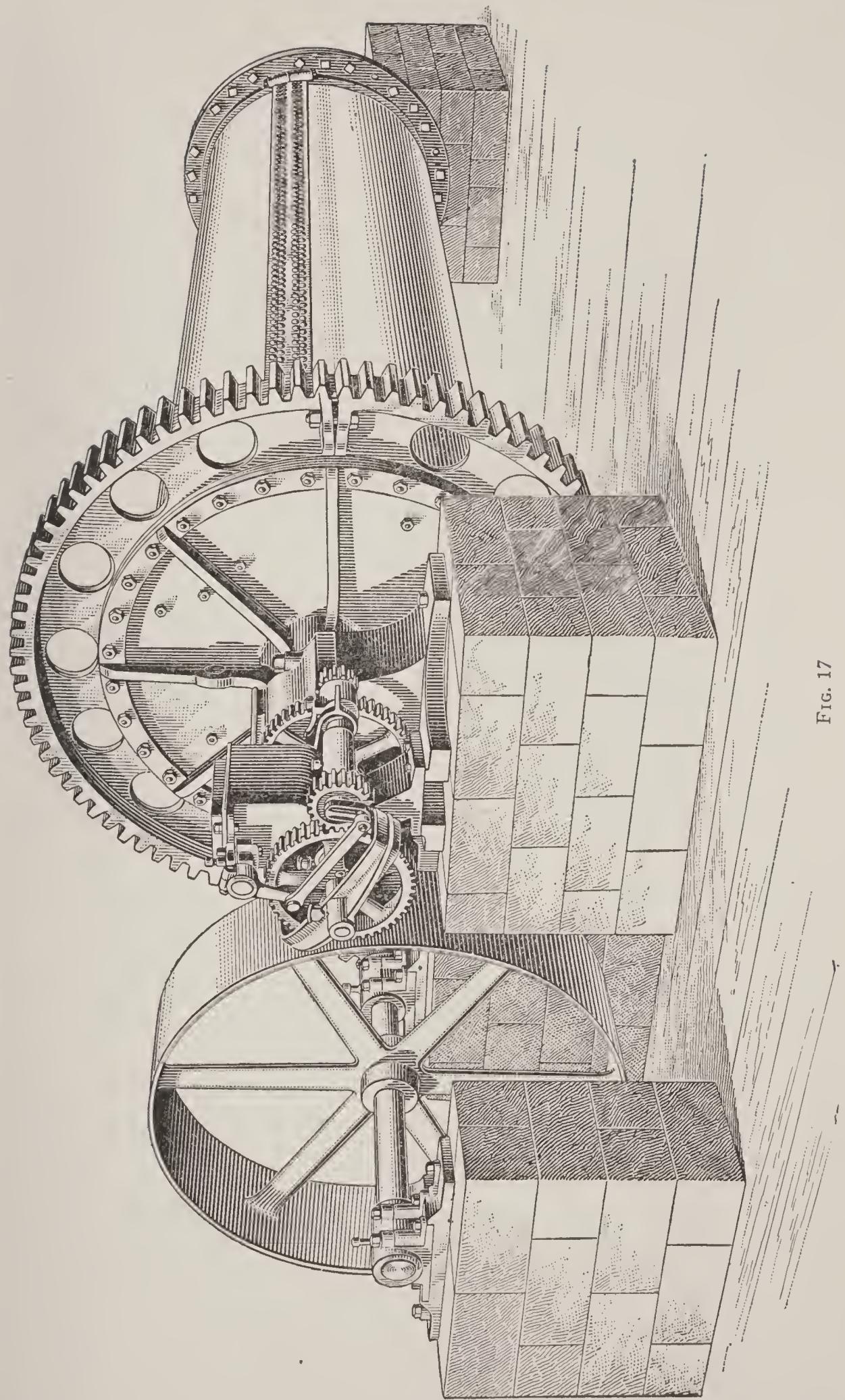
78. It is now quite common practice to replace part and sometimes all of the pebbles by small steel balls or slugs. These slugs are usually about 1 inch long and $\frac{1}{2}$ inch in diameter. When only part of the charge is of slugs a compartment is usually provided at the discharge end of the mill, and this is filled half full of slugs. The use of these slugs increases both the output and power consumption of the mill, but the increase in output is greater than in power consumption. The slugs also increase the fineness of the product.

The capacity of a tube mill will depend on its size, the fineness and hardness of the material fed into it and of the product, the nature of the grinding medium, etc. Table XI gives the output and power requirements of various-sized mills

TABLE XI
CAPACITY OF TUBE MILLS

Size Mill		Operating on Clinker		Operating on Raw Material	
Diam.	Length	Output Barrels per Hour	H. P.*	Output Tons per hour	H. P.*
5′ 6″	22′	20	100	6$\frac{1}{2}$	100
6′ 0″	22′	24	120	8	120
7′ 0″	22′	34	165	12	165

*About double this power is required momentarily in starting.

receiving 20-mesh material of average hardness and grinding to 80 per cent. passing the No. 200 sieve. The mills are lined with silex blocks and charged with pebbles.

The use of a 5-foot compartment on any of the above mills charged with slugs will increase the capacity about 40 per cent. and the power necessary to operate by about 25 per cent.

79. Fuller-Lehigh Mill.—The mill shown in Fig. 18 is a Fuller-Lehigh mill in which the grinding is done by means of a die *a*, and four balls *b* which revolve against it or rather are pushed around by four equidistant arms, or pushers, *c* (shown dotted behind the ball) radiating from a central vertical shaft *d*. The latter revolves at a speed of 130 to

160 revolutions per minute, depending on the size of the mill, and the balls are pressed against the die by centrifugal force.
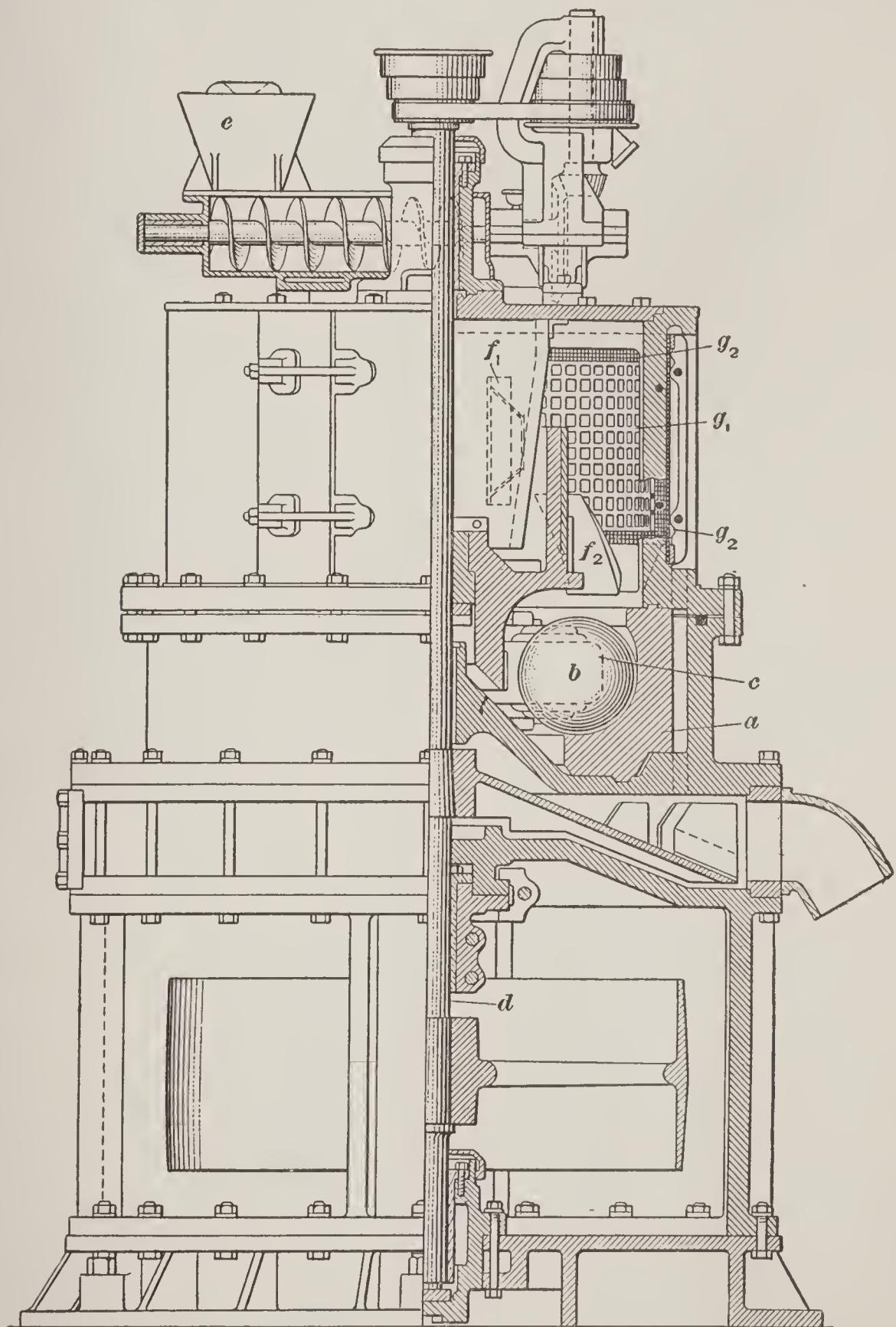

FIG. 18

The material that is ground is fed in at e and eventually falls between the die and balls. There are fans f_1, f_2 attached to

the central shaft and these suck the fully ground material away from the coarser particles and blow it out through a set of screens g_1, g_2 around the upper part of the grinding chamber.
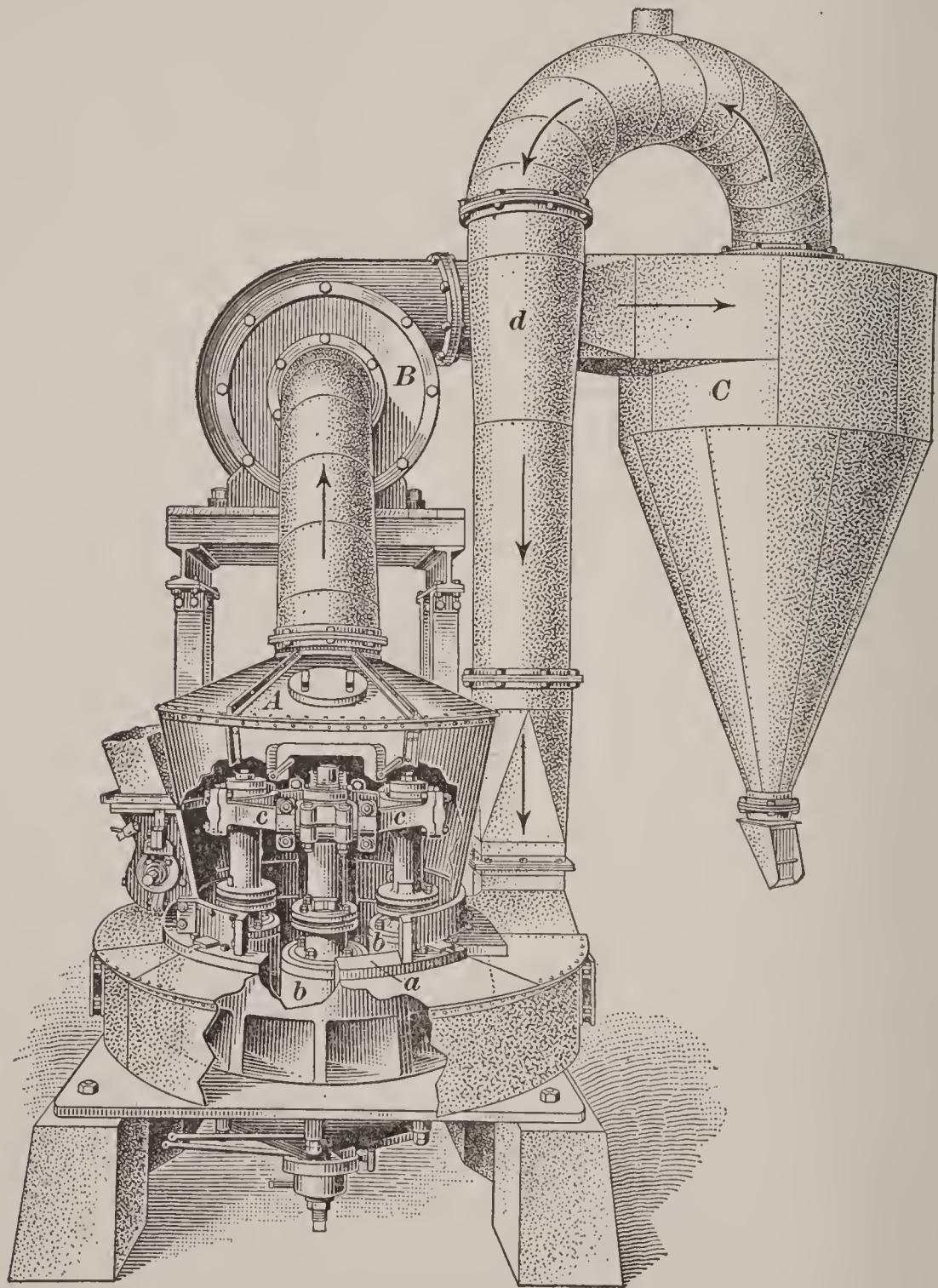

Fig. 19

The fineness is controlled by the mesh of the outer screen g_2, and by the rate at which the material is fed into the mill.

The Fuller-Lehigh mill is made in several sizes, those most used in cement mills being 42-inch and 54-inch, this dimension referring to the diameter of the die. The 42-inch mill will

require about 75 horsepower and will pulverize from 4 to 5 tons of raw material or from 8 to 10 barrels of clinker per hour. The 54-inch mill will pulverize from 8 to 10 tons of raw material or 15 to 20 barrels of cement and requires 125 horsepower.

80. Raymond Mill.—The Raymond mill shown in Fig. 19 consists of three parts: a grinding unit *A*, a fan *B*, and a collector *C*. The grinding unit consists of a die *a* against which four or five rolls *b* revolve. These rolls are suspended from a spider *c* which is rotated by a central shaft. When the shaft revolves the rolls swing out against the die. Above the die is an air separator whose function is so to control the air-currents as to regulate the fineness of the product. The
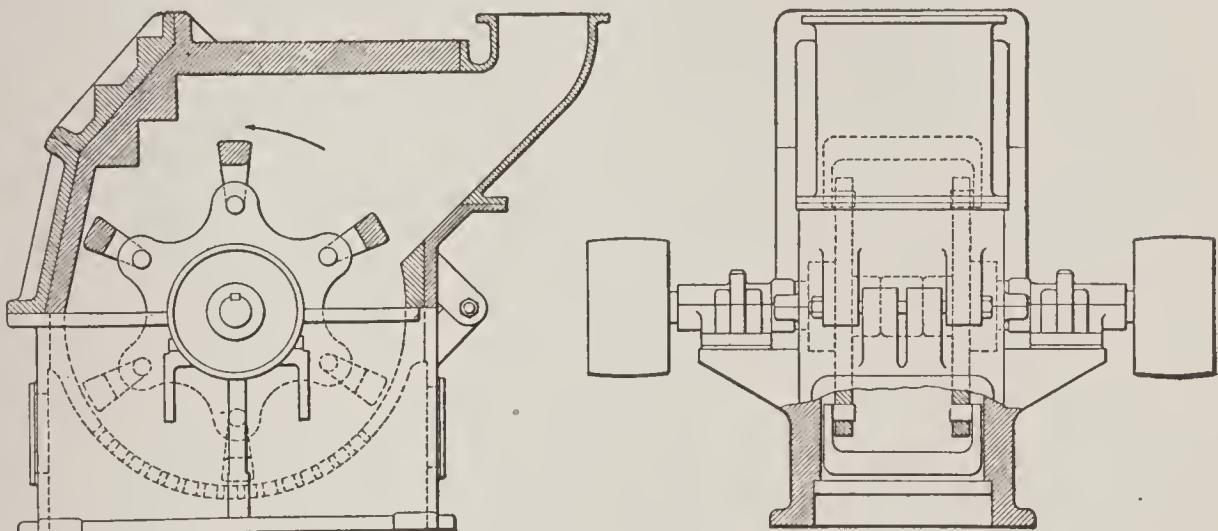

FIG. 20

fan *B* draws the air through the mill and separator, the latter separates the fine material from the coarse and returns the coarse particles to the mill for further grinding. The fine material is carried off by the air, passes through the fan and is discharged into a *cyclone collector* where the ground material is deposited and the air returned to the mill.

The Raymond mill is made into two sizes: four rollers and five rollers. It is suitable for grinding raw material and coal, but not clinker. The four-roller mill will grind about 4 tons of either raw material or coal to a fineness of 96 per cent. passing the No. 100 sieve and requires about 75 horsepower. The five-roller mill has a capacity of 25 per cent. greater than the four-roller mill and requires about 90 horsepower.

81. The Hammer Mill.—This mill is made by numerous machinery manufacturers, and while there are a number of different modifications of the type, they all consist essentially of a number of hinged hammers which revolve around a central shaft inside of a steel case. The hammers crush the material and it passes out through a grid screen as shown in Fig. 20.

Large hammer mills are sometimes used to crush limestone to 2 inches, displacing the small gyratory crushers used in some plants for this purpose. They are most frequently used, however, after these crushers for the preparation of raw material for Fuller-Lehigh and Griffin mills, reducing in this case to $\frac{1}{2}$ inch and are preferred to rolls for this purpose. They are used less frequently in connection with outside screens to prepare material for the tube mill, grinding in this case to 20-mesh. They are also much used for crushing shale, but are not suitable for crushing clinker.

These mills vary greatly in size and may be obtained of almost any desired capacity. When crushing from 3 to $\frac{1}{2}$ inch they require about 2 horsepower per ton per hour of output —that is, a mill grinding 20 tons per hour will require 40 horsepower.

82. Ring Roll Mills.—There are two makes of ring roll mills, which are used to a limited extent for grinding clinker, namely, the Sturtevant and the Maxecon. Mills of this type consist of a vertical die against which three rolls revolve, and the grinding is done between the die and rolls. There is no screening device in the mill itself, but the separation of the fully ground and coarse material is done by an outside device. Either air separators or shaking or vibrating screens may be used for this purpose.

83. Devices Used for Conveying Material in Mills. The material used in the manufacture of cement is usually conveyed from one part of the mill to another by mechanical means. The product of the Gates crusher is carried to the ball-mill bins or to the rolls on belt conveyers or scraper conveyers, and the fine material from the ball mills, Griffin

mills, and the tube mills is conveyed by means of screw conveyers. The elevating is done by bucket elevators of the link-belt form. Slurry and marl are pumped by means of either the compressed-air system or a plunger pump of special design. Dry material is stored in steel bins at every stage of the process in order to have a constant supply for each unit of the grinding system, and marl and slurry are stored in concrete vats or steel tanks and kept in constant motion to prevent the heavier and sandy portions from settling.

BURNING PROCESS AND APPARATUS

84. Burning the Cement Mixture.—Saylor burned his first cement in upright kilns and the first mills in the United States used this form of kiln, which is still employed extensively in Europe. It necessitated the molding of the dry powder into bricks which were then dried and burned. Saylor used Portland cement as a binding material in the making of his bricks and at the American Cement Company's plant coal tar was used, thus doing away with the preliminary drying. In 1885 Ransome obtained a patent in England for burning cement in a revolving furnace. The experiment, however, proved a failure. In the United States a small plant in Oregon also tried to use the Ransome kiln and failed. About the same time the Atlas Portland Cement Company was formed and experiments with Ransome's kiln were begun at first in New York and later with success on the cement rock of the Lehigh Valley.

At first many difficulties were encountered and it was only after the raw material had been ground to an impalpable powder and moistened with water just before introduction into the kiln, that the process became satisfactory. At first the kilns were only 40 feet in length, but it was found more economical to increase the length to 60 feet. Crude oil was used for heating the kiln, the oil being blown into the kiln in the form of a spray. About the year 1898 powdered coal was introduced as fuel. The practice of moistening the finely ground raw material has been discontinued.

85.   Rotary Kiln.—The rotary kiln, which consists of a cylinder made of steel plates bolted together and lined with firebrick, is now universally used in the United States. The length varies from 60 to 250 feet and the diameter of the shell varies from 6 to 12 feet. Formerly kilns were 6 feet in diameter and 60 feet long, but now they are generally 8 feet in diameter and 125 feet long. Kilns are made much larger than this, however, and those measuring 10 feet diameter and 175 feet long are not uncommon, the kilns being made longer as their diameter is increased. They revolve on two or, in some cases, more tires resting on idlers, and are turned by a gear and pinion. The upper end of the kiln projects just inside a short brick flue called the *dust chamber,* which is in turn surmounted by a steel stack. The lower end of the kiln is closed by a movable firebrick hood. The raw material is held in a large steel bin and is introduced into the upper end of the kiln by means of either a screw conveyer working in a water-jacketed case, or else by an inclined cast-iron spout.

The kiln is slightly inclined and as it revolves the material works down toward the burning coal. The first change that takes place is the driving off of the moisture, then the powder begins to lose its carbon dioxide and to form into small, soft, yellow balls; finally, as they work their way down into the hottest part of the kiln, these balls are partly vitrified or clinkered and change to a greenish-black color. The clinker is then burned and drops from the mouth of the kiln through an opening in the hood into either a clinker pit, a rotary cooler, or an elevator that conveys it to an upright cooler.

The inclination of the kiln varies with its size. Small kilns 6 to 7 feet in diameter are usually pitched at an angle of $\frac{3}{4}$ inch per foot to the horizontal, while larger kilns are usually inclined $\frac{1}{2}$ to $\frac{5}{8}$ inch to the foot. The firebrick lining is usually 9 inches thick in the burning zone and 6 inches in the upper part of the kiln. The brick are made to fit the kiln radius and are of high alumina clay. Sometimes a layer of some heat-insulating material such as *sil-o-cel* is placed in the upper part of the kiln between the firebrick and the shell in order to conserve the heat.

The raw material is fed out of the bin in which it is stored, by means of a screw conveyer. This is driven from the kiln shaft so that when the kiln stops revolving the feed stops. Kilns are now usually driven by means of variable-speed motors. When the material burns readily the kilns are operated at their highest speed, but when the fuel fails to burn properly the speed is decreased, allowing the material to remain in the kiln a longer time and giving the heat more time to act upon them.

The slurry of the wet process is fed directly into the kiln without any preliminary drying. In wet burning the upper

TABLE XII

AVERAGE CAPACITY OF ROTARY KILNS

Size		Dry Process		Wet Process	
Diameter Feet	Length Feet	Output Barrels per Day	Coal per Barrel Pounds	Output Barrels per Day	Coal per Barrel Pounds
6	60	200	110	140	150
7	100	400	95	300	135
8	125	650	90	450	120
9	150	1,000	88	700	115
10	175	1,300	85	900	110

50 to 75 feet of the kiln serves to evaporate the water, but from this point on the action in the wet and dry processes is alike.

86. The output and coal consumption of rotary kilns vary with the size of the kilns. Some materials also burn more readily than others. Table XII gives the capacity and fuel consumption of various-sized kilns. As will be seen, the long kilns not only give greater output but use less coal. This is due to the fact that the lengthening of the kiln keeps the raw material in contact with the hot gases for a longer time and consequently allows the raw material to extract the heat from the hot gases better. The wet process takes about one-third more fuel than the dry.

The ordinary rotary kiln is very wasteful of fuel, its efficiency not being more than 20 per cent. The distribution of fuel is about as follows:

	PER CENT.
Employed in decomposing raw materials and forming clinker	20
Heat carried off by the stack gases	41
Heat carried off by the clinker	17
Loss due to radiation, etc.	22
Total	100

87. Fuel.—Coal is generally used as a fuel for the kilns, but natural gas and oil are used in localities where they are cheaper than coal, the choice of fuel being purely a matter of economy. Bituminous coal as high in volatile matter as can be obtained cheaply is preferable. It should be pulverized so finely that at least 90 per cent. of it will pass the No. 100 sieve.

The coal is first run through a set of rolls or a pot cracker to reduce it to 1 inch and under. It is then dried in special forms of rotary driers in which the coal is not heated to the point where combustion or even loss of volatile combustible matter can take place. This is accomplished by allowing the gases from the coal fire to cool somewhat before they are passed over the coal to be dried. Different types of driers secure this result by different means, but in one type commonly employed the result is obtained by enclosing part of the cylinder in the brickwork of the firebox. The coal is thus heated first by the gases from without which are also cooled to a point which will allow them to be brought in contact with the coal. They are then led into the cylinder by means of a suitable flue. The coal is pulverized in either Raymond or Fuller-Lehigh mills. A few of the older plants employ either Griffin mills, or ball-and-tube mills.

The powdered coal is stored in a bin in front of the kiln and fed out of this by means of a screw conveyer, the speed of which can be controlled by some appropriate device so as to give any amount of coal desired. The coal falls from this feed into an injector by means of which it is blown into the

kiln, air being supplied by means of a fan at about 6 to 10 ounces pressure.

The coal-and-air pipe leads just into the kiln and the coal takes fire a few feet from the end of this pipe, burning with a
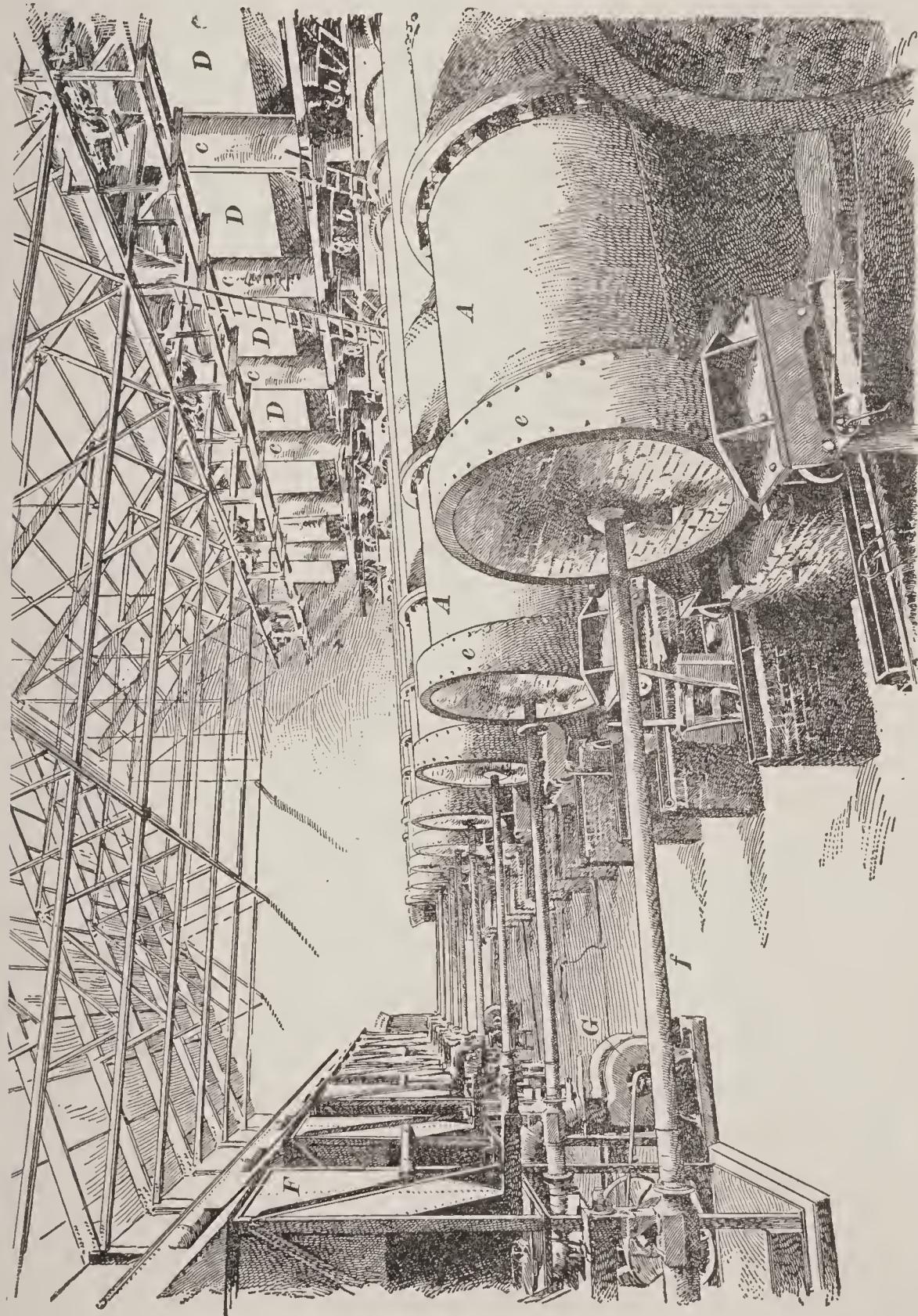
Fig. 21

luminous flame not unlike that of a large blow torch. Only a part of the air necessary for combustion is blown in, the

balance being sucked in through various openings at the front of the kiln.

88.   A battery of ten kilns is shown in Fig. 21, in which *A* is the kiln, *b* the brick-dust chamber, *c* the stack, *D* the raw-material boxes, *e* the hood, *f* the coal pipe to carry the coal into the kiln, *F* the coal boxes, and *G* the fan for supplying air.

89.   Chemical Changes During Burning.—The changes that take place during burning may be summed up as follows:

The carbon dioxide existing in the raw material in combination with the calcium and magnesia as carbonates of these elements is practically entirely expelled.

All the water originally present, whether free, hygroscopic, or combined, is driven off and the carbon and organic matter in the raw material are also burned away.   The iron, the greater part of which is usually present in clay and cement rock in the ferrous condition, is almost completely oxidized.

Most of the sulphur, whether present in the raw material as sulphide, sulphate, or in combination with organic matter, is expelled, all the remainder except a mere trace usually being calcium sulphate.   The alkalies, potash and soda, are partly expelled in the kiln.   Some experiments have shown losses of soda amounting to 19 to 28 per cent., while the loss of potash ran from 46 to 52 per cent.

The changes here mentioned are those which can be detected by chemical analysis.   In addition to these certain combinations take place the most important of which is the union of lime with the silica and alumina to form tricalcium silicate and tricalcium aluminate, respectively, and this union takes place only when the mixture vitrifies or clinkers.

Of these chemical changes the driving off of the water and the carbon dioxide are *endothermic,* so called because they require that heat shall be supplied to bring the changes about, while the burning of the organic matter and the combination of the silica and the alumina with the lime are called *exothermic* because they give off heat.   The difference between these

reactions amounts to 580 B. T. U. per pound of clinker or about 220,000 B. T. U. per barrel. The latter figure is equivalent to 15½ pounds of good coal (14,000 B. T. U. per pound). This is much below the amount of fuel actually used and the difference between the heat required and that used is lost by the heat in the clinker and in the stack gases and by radiation from the kiln shell as already explained.

90. Degree of Burning.—Properly burned Portland cement clinker is greenish-black in color, of a vitreous luster, and, when just cooled, usually sparkles with little, bright, glistening specks. It forms in lumps from the size of a walnut down, with here and there a larger lump. Underburned clinker, due either to a low temperature in the kilns or to an overlimed mixture, lacks the vitreous luster and the glistening specks. The failure to sparkle, however, is not necessarily characteristic of underburned clinker, though the sparkle itself is never seen in underburned clinker, as the rate of cooling, etc., affects the appearance of sparkle somewhat. If much underburned, the clinker is brown, or has soft brown or yellow centers. Clinker low in lime, unless very carefully burned, usually has brown centers also, but the centers are hard and thoroughly vitrified.

There is probably a relation between fineness, time in the burning zone, and temperature of the kiln. It is a well-known fact that fine materials require less time for burning or a lower temperature than do coarser ones. Likewise less time is required in a high temperature than is needed in a lower one, etc. The composition also affects all three of these conditions. High-lime cements require higher temperatures, finer grinding, or longer time in the kiln than do low-lime cements. It is understood that varying one condition may call for a change in the others. The time of burning is controlled by slowing the speed of the kiln or by lengthening the hot zone, which is brought about by cutting down the draft. The actual temperature of cement kilns as measured by optical pyrometers does not seem to vary widely and ranges between 2,300° F. and 2,600° F.

91.   Waste Heat Recovery.—As previously explained, about 40 per cent. of the fuel supplied to the kiln is represented in the heat of the waste gases. The latter leave a dry-process kiln at a temperature of from 1,500° F. to 1,800° F. and a wet-process kiln at a temperature a few hundred degrees lower. It has recently been found that by drawing the gases from the kilns through water-tube boilers a considerable amount of heat contained in the waste gases could be recovered. The boilers are connected to the dust chamber by means of a short flue and the gases are drawn through the boiler by means of a draft fan, care being exercised to prevent entrance of cold air. Usually an economizer is placed after the boiler to utilize still further the heat in the gases by heating the feedwater for the boiler. The heat utilized by such a waste-heat boiler system amounts in the case of a dry-process plant to about $11\frac{1}{2}$ boiler horsepower hours per barrel of cement produced. With modern steam turbines directly connected to electric generators enough power is provided to operate the entire cement plant.

92.   Dust From Cement Kilns.—Normally in the dry process from 3 to 5 per cent., and in the wet process possibly a little less, of the raw material is carried out of the kilns by waste gases. This is the finest portion of the material and it is often transported by the winds and air a considerable distance from the plant and deposited on the surrounding country. Occasionally complaints have been made on account of this dust, particularly when the mills have been located in rich agricultural communities or near cities and towns.

It has in some cases, therefore, been necessary to collect this dust in order to prevent its becoming a nuisance to the people living near the plants. Two methods have been devised for collecting the dust: (1) by means of water sprays, and (2) by electrical precipitation (Cottrell system). In the former the gases are led through long chambers in which they are thoroughly washed by means of water sprays, the drops of water carrying down the dust. In the latter the gases are passed through a large number of iron pipes through the center of each of which an iron wire passes. The pipe and wire are

connected to the terminals of a high-potential (45,000 to 80,000 volts) direct electric current. There is a silent discharge of electricity from the wire to the tube, and the effect of this is to precipitate the dust, the larger portion collecting on the tube. At stated intervals the flow of current is interrupted and the dust rapped off the pipe into hoppers located below.

93. Potash Recovery.—Attention has already been called to the volatilization of potash from the raw materials during burning. This amounts on an average to about 2 pounds of K_2O for every barrel of cement burned. By either of the two methods mentioned a considerable proportion of this potash can be recovered. In the case of the water spray system the potash goes into solution and may be recovered by evaporation from the water in the form of sulphate. In the case of the electrical precipitation method, the dust may be leached with water, when the potash will go into solution. The latter is filtered from the solid matter and the potash recovered as above stated. The dust itself contains from 3 to 10 per cent. of potash, depending on the amount in the raw materials, efficiency of the recovery apparatus, etc. As it also contains considerable lime, the dust has real value as a potash-lime fertilizer and can be sold for this purpose. If salt is added to the raw materials the amount of potash volatilized is increased, and, incidentally, the dust collected will be richer in potash. During the war when potash could not be obtained from Germany, the world's source of supply, potash was collected and sold at a profit at a number of cement mills. With the return of the German supply the extraction of potash from the dust was not so profitable. Neither is it always possible to make good cement from the dust recovered and most attempts to use it so have failed. It is highly desirable, therefore, where dust must be collected to find a local market for this very valuable potash-lime fertilizer.

94. Cooling the Clinker.—The clinker is usually at a temperature of 1,800° F. to 2,000° F. when it leaves the kiln. It is almost the universal practice to spray it with water just

as it leaves the kiln. This not only cools the clinker but also seems to fix its chemical composition better. Formerly the upright cooler, which consists of an upright sheet-iron cylinder about 8 ft.×35 ft., was used extensively to cool the clinker. The cylinder is provided with baffle plates and shelves, and when the clinker falls over these, it is exposed to a current of air blown in by a fan and cooled. Revolving coolers are also used. These consist of a cylinder similar in construction to a kiln except that they are smaller and unlined. A cooler for an 8 ft.×125 ft. kiln is usually 5 feet in diameter and 50 feet long. The coolers are pitched at an angle and the clinker falls directly from the kiln into the upper end and works its way through. A current of air is sucked through the cooler by means of the kiln draft passing into the kiln. These coolers, therefore, serve not only to cool the clinker but also to preheat the air for combustion, and so effect an economy in operation. Many of the newer mills do not employ a grab bucket and crane to handle the clinker, but cool their clinker in piles with the help of water.

It is now the general practice before grinding to season the clinker by allowing it to remain in large piles exposed to the weather for a period of 4 to 6 weeks, and even much longer. It has been found that clinker so seasoned not only grinds easier but cement made from it is more apt to be sound and have correct setting properties. The seasoning no doubt causes the slaking of the free lime present and this in turn breaks down the structure of the material. The mixing of a large quantity of clinker burned at different times also promotes uniformity of the product. The clinker is usually handled in and out of storage either by means of a system of conveyers over and under the pile or else by a grab bucket and overhead or locomotive crane.

95. Grinding the Clinker.—After cooling, the clinker is ground by one of the following systems:

1. Tube mill preceded by: (*a*) ball mill; (*b*) kominuter; (*c*) Griffin mill; (*d*) Hercules mill, Maxecon mill; (*e*) Sturtevant mill.

2.   Griffin mill preceded by : (*a*) ball mill provided with perforated plates and without screens; (*b*) crushing rolls; (*c*) pot cracker.

3.   Fuller mill preceded by same equipment as given above for Griffin mill.

4.   Sturtevant mill, preceded by: (*a*) crushing rolls; or (*b*) pot cracker, followed by (*c*) screen; or (*d*) air separator.

5.   Maxecon mill, preceded by: (*a*) crushing rolls; or (*b*) pot cracker, followed by (*c*) screens; or (*d*) air separator.

In order to regulate the set of the cement it is necessary to add sulphuric acid in some form or other, usually in the form of gypsum. This can be most readily done before grinding, insuring a thorough mixing. When cement becomes quick-setting on storage, it can often be made slow-setting by addition of finely ground plaster of Paris. This is usually done by adding at regular intervals a quantity of plaster to the cement as it is being carried from the stock-house bins to the packers. The conveyer does the mixing.

96.   Storage of Cement.—From the clinker mills the cement is conveyed to the stock house. At the older plants this is a long, low frame building provided with wooden bins. The cement is brought in by an overhead screw conveyer and dropped into the proper bin by means of slides and spouts. A screw conveyer runs along either the center of the stock house with bins on each side or along each side of the stock house with the bins in the middle. When a bin is to be opened for packing, the sideboards are removed and the cement is allowed to run into the conveyer freely as long as it will. When the cement ceases to run freely, it must either be pulled to the conveyer by means of a long-handled scraper having a broad blade or else put into barrows and wheeled to the conveyer. The screw conveyer conducts the material to the packing machines.

A more modern adaptation of this old stock house has concrete side walls and either frame or concrete partitions between the bins. The conveyers are in tunnels running underneath bins which have sloping bottoms. This arrangement allows the cement to be drawn out of the bins and into the conveyer by

gravity. The most recent type of stock house is shown in Fig. 22 and is built on the order of a grain elevator with high reinforced-concrete tanks or silos for bins. These bins are usually 20 to 25 feet in diameter and 50 to 80 feet tall.
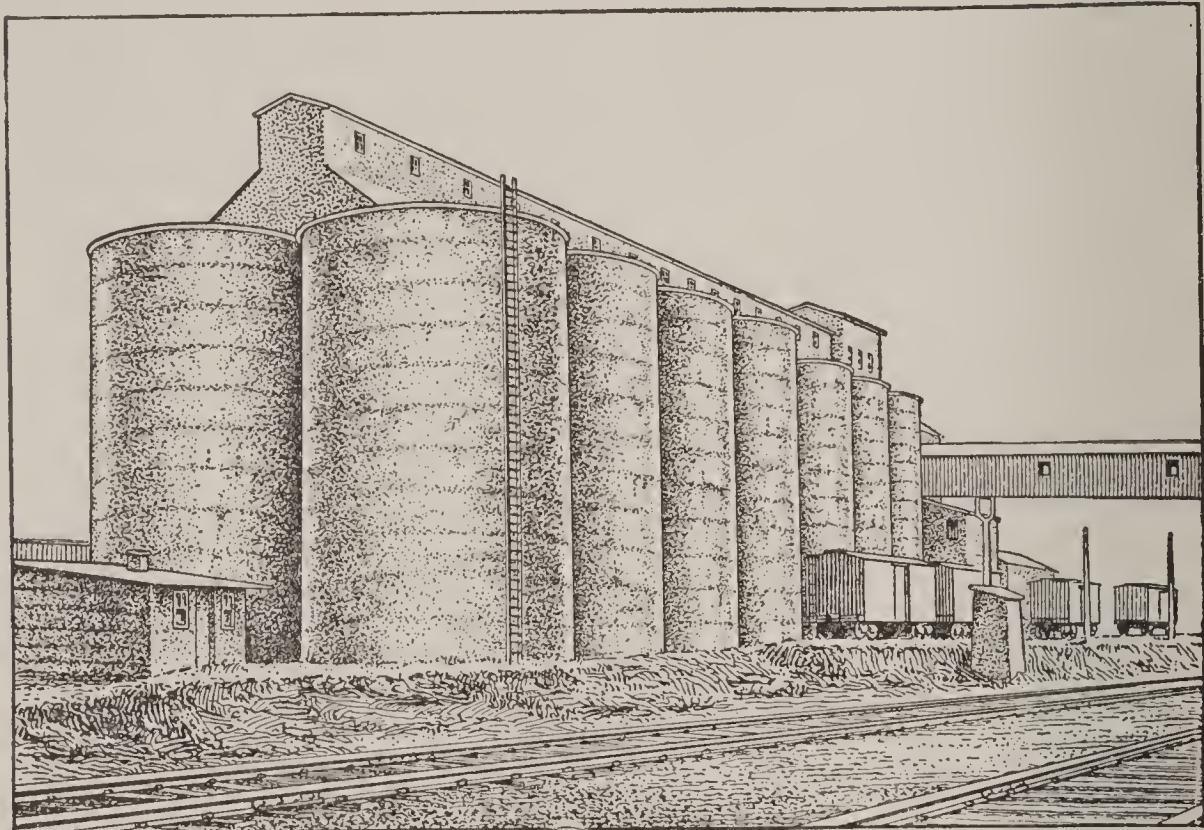

Fig. 22

Tunnels containing the conveyers run under the silos and permit the silos to be emptied almost completely. The advantages of this type of stock house over the older ones are: cheapness to build, compactness, and the thoroughness with which the bins can be emptied without resorting to manual labor.

PACKING CEMENT

97. Cement is usually packed into paper or cloth bags. It is rarely packed in barrels, although the barrel is still considered the standard unit of quantity and consists of 376 pounds net. There are four sacks to the barrel, and each bag contains 94 pounds net. Barrels are packed by means of machines similar to those used for packing flour, and occasionally sacks are also packed in the same way.

Almost all cement is now put into bags by the Bates system. This system depends upon a novel bag, the fundamental feature

of which is a valve in one corner. This is made by turning down and sewing in one corner. When pressure is applied to this valve, as when cement comes against it, the valve closes. With this bag the order of filling is reversed and the bag is first tied by means of a wire tie and then filled through the valve. The machine used for filling is provided with three or four tubes. The valve of the bag is slipped over one of these tubes, a gate is opened, and cement is forced through the tube into the bag. As the bag fills, it rests on a cradle. When the desired weight of cement is in the bag, the cradle, which is balanced by weights, falls and cuts off the flow of cement. The attendant merely slips the bag on the tube, starts the flow of cement, and removes the sack when full. Otherwise the operation is automatic.

Very little cement is now packed in wooden barrels and only for export trade. The cement is packed just as it is about to be shipped, and the bags or barrels are trucked directly to the cars. For this reason the packing room should be arranged so that the cars to be loaded can be brought alongside of the room, and a shed roof is run out over the cars so that the loading will not be interrupted by rainy weather. The floor of the packing room should be level with the floor of the cars to be loaded.

Cloth bags are used more than anything else for the packing of cement. The consumer is charged a fixed sum for the bag and is allowed a credit of the same amount for it when it is returned. All bags are marked with the label of the brand, so that each manufacturer knows his own bags. Barrels and paper bags are sold to the customer and are not returnable.

POWER PLANT

98. The balance of the equipment of a cement plant is similar to that of metallurgical and chemical plants. A large quantity of power is required in grinding the raw materials and the hard clinker. The power plant of a modern cement mill is, therefore, a large one. The size of the power plant will depend to some extent on the hardness of the raw material and on other considerations, but in general it may

be said that there will have to be provided 1 horsepower for each barrel of cement ground per day—that is, a 3,000-barrel-per-day cement plant will require about 3,000 horsepower. Roughly speaking, about two-thirds of this power is required to grind the raw materials and the clinker, and the balance is used by the kilns and other machinery.

All modern cement plants employ motor drives. In this system the power plant consists of either steam turbines or Corliss engines directly connected to powerful electric alternating-current generators, which furnish the current transmitted to various parts of the mill by copper cables. The machines are then driven by individual motors. In some cases the motors are directly connected to the machinery, but generally belts or chain drives are employed. The kilns are driven by variable-speed motors, and Fuller and Griffin mills are driven by vertical motors. Owing to the large amount of power required, the equipment must be first-class and carefully laid out.

GENERAL CONSIDERATIONS

99. Cement plants are no longer built in this country of a capacity smaller than 1,000 barrels per day, and generally the mills are from 2,500 to 3,000 barrels per day. There are a number of mills, however, which produce very much more than this quantity of cement.

A modern Portland cement plant exclusive of the value of real estate, mineral deposits, stock of bags, working capital, etc., will cost about $2.25 per barrel of cement produced annually. In other words, a plant producing 3,000 barrels daily will make about 1,000,000 barrels annually and will cost about $2,250,000. In 1914, when conditions were considered normal, a cement plant cost about $1.00 per barrel of annual production. The cost of manufacturing cement varies with different localities, but was approximately $1.50 per barrel during the abnormal period of the war. During normal conditions, the cost per barrel of cement is approximately 75 cents.

MANUFACTURE OF CEMENT

(PART 2)

TESTING OF PORTLAND CEMENT

PHYSICAL TESTS

1. Introduction.—Tests of cement may be classified as physical and chemical. The value of a cement is determined largely by physical tests, not only because in actual practice the cement is subjected to physical stresses, but also because the value of cement depends not so much on the percentage of lime, silica, and alumina present, as on the thoroughness with which these have combined with one another. Moreover, physical testing does not require so much previous training as is necessary to fit one for making chemical analyses. It must not be inferred, however, simple as the directions may seem, that any one can become an expert physical tester in a few days. Time and practice only can make a skilful physical tester, as it has been repeatedly shown that the same cement in the hands of two different testers may give very widely differing results. In fact, some very high-grade cements have been condemned on many occasions, owing to a lack of experience on the part of the tester, or because of the neglect of a skilful operator to observe some of the numerous precautions necessary to assure uniform results.

2. All cement is tested under what are known as "the Standard Specifications and Tests for Portland Cement," drawn up by a joint committee of the American Society for Testing Materials, the American Society of Civil Engineers, the Port-

land Cement Association, the United States Government, and other organizations. These specifications, as adopted in 1917, are as follows:

STANDARD SPECIFICATIONS AND TESTS FOR PORTLAND CEMENT

1. Portland cement is the product obtained by finely pulverizing clinker produced by calcining to incipient fusion an intimate and properly proportioned mixture of argillaceous and calcareous materials, with no additions subsequent to calcination excepting water and calcined or uncalcined gypsum.

I. Chemical Properties

2. The following limits shall not be exceeded:

	Per Cent.
Loss on ignition	4.00
Insoluble residue	.85
Sulphuric anhydride (SO_3)	2.00
Magnesia (MgO)	5.00

II. Physical Properties

3. The specific gravity of cement shall be not less than 3.10 (3.07 for white Portland cement). Should the test of cement as received fall below this requirement, a second test may be made upon an ignited sample. The specific gravity test will not be made unless specifically ordered.

4. The residue on a standard No. 200 sieve shall not exceed 22 per cent. by weight.

5. A pat of neat cement shall remain firm and hard, and show no signs of distortion, cracking, checking, or disintegration in the steam test for soundness.

6. The cement shall not develop initial set in less than 45 minutes when the Vicat needle is used, or 60 minutes when the Gilmore needle is used. Final set shall be attained within 10 hours.

7. The average tensile strength in pounds per square inch of not less than three standard mortar briquettes composed of one part cement and three parts standard sand by weight shall be equal to or higher than the following:

Age	Storage of Briquettes	Tensile Strength, in Pounds per Square Inch
7 days	(1 day in moist air, 6 days in water)	200
28 days	(1 day in moist air, 27 days in water)	300

8. The average tensile strength of standard mortar at 28 days shall be higher than the strength at 7 days.

III. Packages, Marking, and Storage

9. The cement shall be delivered in suitable bags or barrels with the brand and name of the manufacturer plainly marked thereon, unless shipped in bulk. A bag shall contain 94 pounds net. A barrel shall contain 376 pounds net.

10. The cement shall be stored in such a manner as to permit easy access for proper inspection and identification of each shipment, and in a suitable weather-tight building which will protect the cement from dampness.

IV. Inspection

11. Every facility shall be provided the purchaser for careful sampling and inspection at either the mill or at the site of the work, as may be specified by the purchaser. At least 10 days from the time of sampling shall be allowed for the completion of the 7-day test, and at least 31 days shall be allowed for the completion of the 28-day test. The cement shall be tested in accordance with the methods hereinafter prescribed. The 28-day test shall be waived only when specifically so ordered.

V. Rejection

12. The cement may be rejected if it fails to meet any of the requirements of these specifications.

13. Cement shall not be rejected on account of failure to meet the fineness requirement if upon retest after drying at 100° C. for 1 hour it meets this requirement.

14. Cement failing to meet the test for soundness in steam may be accepted if it passes a retest, using a new sample at any time within 28 days thereafter.

15. Packages varying more than 5 per cent. from the specified weight, may be rejected; and if the average weight of packages in any shipment, as shown by weighing 50 packages taken at random, is less than that specified, the entire shipment may be rejected.

3. Specific Gravity.—The test is designed to detect underburning and adulteration. Unfortunately for any conclusions that might be drawn as to the latter, low specific gravity is often, and, indeed, is usually caused by aging or seasoning of the cement, so that to reject a cement because of a low specific gravity may be to reject it because it has been well seasoned. It is now generally acknowledged that cement is greatly improved by seasoning, as the water and carbon dioxide

absorbed from the air react with any free or loosely combined lime that might otherwise cause the cement to be unsound. As the cement absorbs these constituents from the air, its specific gravity becomes less and less. The specific-gravity test is not of any value in detecting mixtures of natural cement and Portland, sold as the latter, because some natural cements notably those from the Lehigh District in Pennsylvania have a specific gravity that is practically as high as that of Portland cement.

The determination of the specific gravity of cement should always be made on a sample as received, but if the cement fails to pass the test a second trial may be made upon a sample ignited at a red heat.

4.   Detection of Adulteration.—Should the cement show a low specific gravity, the residue left by sieving from 100 to 200 grams of the cement through a 100-mesh sieve should be examined under a low-power microscope or a pocket magnifier to see if the cement has been adulterated. Slag may be detected by its color and fracture, the former being bluish or white and the latter sharp and irregular, while Portland-cement clinker is almost black or dark brown and is in more or less rounded particles. Limestone and cement rock may be detected by their appearance and by effervescence with acids. The foreign particles may be picked out with a pair of fine tweezers and further identified by grinding fine in an agate mortar and analyzing. If the cement has been ground in tube mills the residue will also contain flint from the pebbles. This flint is not an adulteration and may be distinguished from slag because, after grinding, its particles are insoluble in acid. Cements may also contain particles of iron from the Griffin mills or ball mills. These are magnetic and may be detected by this property.

5.   The Specific Gravity Test.—The method of conducting the test is as follows: Sixty-four grams of cement is carefully weighed on scales that should be sensitive to at least .005 gram. The flask, Fig. 1, is filled with kerosene free from water, or with benzine not lighter than 62° Baumé, which have no action on the cement, to some point on the stem between the

zero and the 1-cubic-centimeter mark. The cement of the same temperature as the liquid is slowly introduced into the flask, care being taken that the cement does not adhere to the sides of the flask above the liquid and that all air bubbles are removed. After all of the cement has been introduced into the flask the level of the liquid will rise to some division of the graduated neck. The volume of liquid displaced by the 64 grams of cement is the difference between the initial and the final reading, and the specific gravity of the cement is 64 divided by that quantity. For example, suppose that the initial reading on the flask is .42 and that the final reading is 20.93; then the displaced volume will be $20.93 - .42 = 20.51$ cubic centimeters and the specific gravity will be $64 \div 20.51 = 3.12$.

The apparatus must be protected from changes in temperature while in use, because even touching the flask with the fingers will change the volume of the liquid noticeably. The flask should be immersed in water during the test to prevent variations in the temperature of the flask and contents. The variation in temperature should not exceed .5° C. (.9° F.) and the results of repeated tests should agree within .01.

Ground Glass Stopper

6 C C Capacity at 20°C

17 CC Capacity at 20°C

1 CC Capacity at 20°C

24.3 CM.

FIG. 1

A convenient method of cleaning the apparatus is to invert the flask over a large vessel preferably a glass jar, and shake it vertically until the liquid begins to flow freely; it is then held still in a vertical position until empty. The remaining traces of cement can be removed in a similar manner by pour-

ing into the flask a small quantity of clean liquid and repeating the operation.
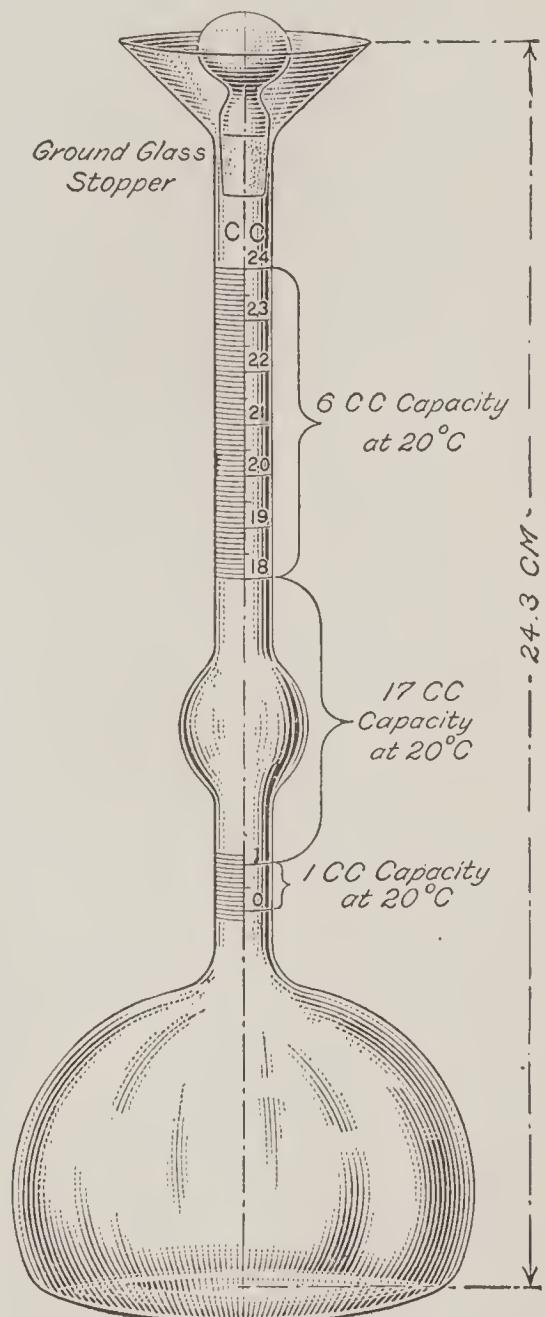
6. Fineness.—The fineness of a cement is determined by sifting a sample through a 200-mesh sieve, or, in other words, a sieve having that number of meshes per linear inch. The size of each of the meshes nominally is .0029 inch, but the actual opening depends on the gauge of the wire. That for the 200-mesh sieve (No. 200) should be .0021 inch in diameter. The United States Bureau of Standards will measure and report on any sieve submitted to them and a sieve which has been passed by them should always be used if possible. Any sieve is considered standard which has between 192 and 208 meshes and in which the diameter of the wire is between the outside limits of .0019 and .0023 inch. The cloth should be carefully placed in the frames so as not to stretch and distort the meshes. The frame itself should be of brass 8 inches in diameter and provided with a pan and cover.

The standard method of making the tests is as follows: Exactly 50 grams of cement (weighed on a balance sensible to at least .01 gram) is placed in the No. 200 sieve, which should be thoroughly clean and dry. The pan and cover should be attached to the sieve and the latter held in a slightly inclined position with one side about $1\frac{1}{2}$ to 2 inches lower than the other. The sieve in this position is moved rapidly back and forth at the rate of about 150 strokes per minute, at the same time gently striking the upper side against the palm of the other hand on the upward stroke. The sieve should be turned every twenty-five strokes about one-sixth of a revolution in the same direction, so as to make a complete revolution every minute. During the operation the cement should be kept as evenly distributed over the surface of the sieve as possible. The operation is continued until not more than .05 gram passes through the sieve in 1 minute of continuous sieving.

Instead of using the pan and cover to the sieve, a good plan is to do the sieving over a sheet of clean paper or oilcloth and to take care that the cement is not bounced over the top of the sieve. When it is desired to ascertain whether or not

the operation has been completed, the material on the paper is rolled to one side by lifting the edge of the paper, thus exposing a clean surface over which the sifting may be continued and the amount passing through the sieve observed. An experienced operator will be able to tell by his eye and sense of time when the operation is finished without recourse to watch, balance, and weights.

The residue on the sieve is weighed. The fineness is then found by multiplying the weight of residue so found, by 100 and dividing by the weight of cement taken. The result is reported as the residue on the No. 200 sieve. Of course, a simple way to calculate the percentage of residue when exactly 50 grams of the sample is taken, is to multiply the weight of the residue in grams by 2. The houses supplying apparatus for cement-testing usually list very convenient little balances for fineness determinations in which the percentage of residue can be directly read off.

Mechanical devices for sieving are on the market, but are not considered standard. They are, however, convenient, particularly at the cement plant where many fineness determinations are made daily. Formerly cement was tested through a No. 100 sieve, also, but this is not required now. Another method of sieving which is often used but which is not standard, is, instead of striking one side against the palm of the hand to bounce one side of it gently up and down on a small block of wood, taking care that none of the material spills over the top of the sieve. The addition of a few shot to the contents of the sieve also greatly hastens the operation of sieving, as the bouncing of the shot on the wire cloth of the screen keeps the meshes of the latter open. To separate the shot from the coarse material preparatory to weighing the latter, the mixture is passed through a 10- or 20-mesh screen. This method of sieving is particularly effective for taking the fineness of raw material, hydrated lime, and materials of this character.

7. Importance of Fine Grinding.—Generally the finer the grinding the more active is the reaction in setting, though a fine cement is not necessarily quick-setting. While a very

finely ground cement may not develop as high a neat tensile strength as a coarser one, its tensile strength is greater in sand tests, and as this is more nearly the test in actual practice, it serves as a better indication. The cementing value, or adhesive power, of a cement depends on its fineness, and it is claimed that the higher results on neat tests with coarse cement is due to the fact that the coarser particles act as sand, thereby combining both cohesive and adhesive effects. However this may be, it has been conclusively shown by a series of tests on the same cement that the samples which were coarsely ground gave higher neat tests while those finely ground gave higher sand tests.

8. Limitations of the Sieve Test.—While the sieve test is a very good check on the grinding at the mill, too great confidence should not be placed in it when examining new brands of cement, as a cement ground so that 85 per cent. of it will pass a No. 200 sieve may not in reality be so fine as one ground only 75 per cent. fine. The cementing value of Portland cement depends on the percentage of those infinitesimal particles known as *flour,* and no sieve is fine enough to tell the quantity of these particles present. The particles retained on the No. 100 and No. 200 sieves have no binding power when used with sand and undoubtedly much of the cement that passes the No. 200 sieve has very little if any binding power. The products of the Griffin mill and of the ball and tube mills probably differ much in the percentage of flour present, even when testing the same degree of fineness on the 200-mesh sieve. Even with the ball- and tube-mill system, one ball mill and two tube mills would probably give a product with a higher percentage of flour than one tube mill and two ball mills even if the cement is ground to the same sieve test. The size of the screen on the ball mills probably also influences the percentage of flour in a product of a certain fineness.

9. Mixing Cement Pastes and Mortars.—The tests that follow are to be applied to either cement pastes or mortars. The term *cement paste* is used to designate a mixture of

cement and water only, while the term *mortar* applies to mixtures of cement, sand, and water.

In making tests with either pastes or mortars, the quantity of dry material to be mixed at one time should not be more than 1,000 grams, nor less than 500 grams. If the mixture is cement and sand, the two should not weigh more than 1,000 grams. The temperature of the room and the mixing water should be as nearly 70° F. as possible.

The dry materials are first weighed and placed on a large plate of thick glass, a slab of slate or stone, or a sheet of brass about 2 feet square and a crater formed in the center. The proper percentage of clean water is then poured into the crater and the material on the outer edge is turned into the crater by means of a trowel. As soon as the water has been absorbed, which should not require more than $\frac{1}{2}$ minute, the operation is completed by kneading the cement with the hands vigorously for an additional 1 to 3 minutes, the process being similar to that used in kneading dough. A sand-glass affords a convenient guide for the time of kneading. During the operation of mixing the hands should be protected preferably by rubber gloves.

Fig. 2

10. Normal Consistency.—In order to determine the setting time, strength, etc., of cement, it is necessary to establish a standard of consistency, as the percentage of water added to a sample of cement influences its setting time. This standard of consistency is termed the *normal consistency* of cement and under standard rules is determined by means of the Vicat apparatus shown in Fig. 2. This device consists of a frame *a* that bears a movable rod *b* weighing 300 grams, one end *c* being 1 centimeter in diameter for a distance of 6 centimeters and the other having a removable needle *d*, 1 millimeter in diameter and 6 centimeters long. The rod is reversible, moves
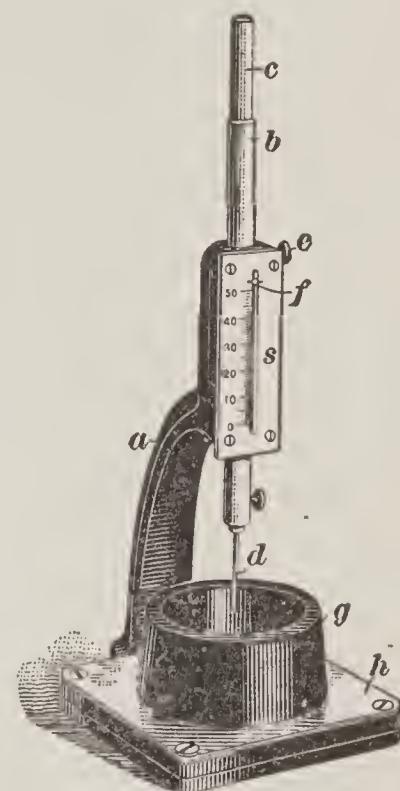
freely up and down, and can be held in any desired position by the screw c. To the rod b is attached an indicator f that moves over a scale s (graduated to millimeters) attached to the frame. The mortar is held by a conical hard-rubber ring c which rests on a glass plate h. The ring c is 7 centimeters in diameter at the base and 4 centimeters high.

In making the determination of consistency the same quantity of cement as will subsequently be used for each batch in making the briquettes (but not more than 1,000 nor less than 500 grams) is kneaded into a paste, as already described, and quickly formed into a ball with the hands, the operation being completed by tossing the ball six times from one hand to the other, the hands being held 6 inches apart. The ball resting in the palm of one hand is then pressed into the larger opening of the conical rubber ring g held in the other hand, completely filling the ring with the paste. The excess at the larger end is then removed by a single movement of the palm of the hand and the ring placed with the larger end downward on the glass plate. The mortar rests on this glass plate and the upper, or smaller, surface is smoothed off with a trowel held at a slight angle with the top of the ring. During the filling of the ring care must be taken not to compress the paste.

The rod is now so adjusted that the lower end of the cylinder is in contact with the surface of the cement mixture. The indicator is read, the rod is quickly released by a turn of screw and the cylinder, owing to its weight, penetrates the plastic cement mixture. The depth of penetration is read off the scale.

The paste is of normal consistency when the cylinder penetrates the mass 10 millimeters below its surface within $\frac{1}{2}$ minute after being released. Great care must be taken to fill the ring exactly to the top. The trial pastes are made with varying percentages of water until the correct, or normal, consistency is obtained.

11. Setting Time.—The term *set* is used to define the change undergone by the cement passing from the plastic to the solid state and has no bearing at all on the hardening of

the cement. It is usually divided into two arbitrary periods called the *initial set* and the *final set*.

12. Method of Determining Setting Time.—To test the set, a paste of normal consistency is molded and placed under the rod, Fig. 2. The needle is then carefully brought in contact with the surface of the paste and quickly released. The setting is said to have commenced—that is, the initial set takes place—when the needle ceases to pass a point 5 millimeters above the upper surface of the glass plate within $\frac{1}{2}$ minute and is said to have terminated—that is, the final set occurs—the moment the needle does not visibly sink into the mass.

The test pieces, or rings filled with the cement pastes should be stored in moist air during the test. This is accomplished by placing them on a rack over water contained in a pan and covered with a damp cloth, the cloth being kept away from the test pieces by means of a wire screen, or they may be stored in a moist box or closet. Care should be taken to keep the needle clean, as the collection of cement on the sides of the needle interferes with its penetration, while cement on the point of the needle tends to increase its penetration.

The determination of the time of setting is only approximate, being materially affected by the temperature of the mixing water, the temperature and humidity of the air during the test, the percentage of water used, and the amount of kneading and molding the paste receives.

13. Gilmore's Needles.—The test proposed by General Gilmore, U. S. A., for determining setting properties is the one most frequently used in the United States. It consists in mixing neat cement to a stiff plastic consistency, making cakes 2 or 3 inches in diameter and $\frac{1}{2}$ inch thick from this mixture, and observing how much time elapses before they will bear a needle 1/12 inch in diameter and weighted with $\frac{1}{4}$ pound. When the cake is firm enough to bear the needle the time is noted as the beginning of the set, or in other words, the time of initial set. The cakes, or pats, should be made with a flat top, so as not to catch the edge of the needle. Trials are next made

every now and then with a 1/24-inch needle weighted with 1 pound. The time at which the cake is firm enough to bear the needle, is noted as the end of the set. The Gilmore needles, or wires, illustrated by Fig. 3, are much more convenient to use when many samples have to be tested, as the pats themselves do not have to be lifted from the moist closet or table in order to apply the needle. While the Vicat needle unquestionably is a more scientific instrument and should be used in all cases where great precision is required in making tests, as in settling disputes, etc., still, for ordinary inspection work where all that is needed is the assurance that the cement will not set before it is laid in position, and that after it is so placed it will harden in a reasonable time, the simpler and less expensive Gilmore needles will answer the purpose just as well as the more expensive Vicat apparatus. Gilmore's needles are the ones generally used both by manufacturers and by engineers in determining the set-

FIG. 3

ting time of cement and most men called on to test and use cement are familiar with the terms *initial* and *final set* as used in connection with these needles.

14. Ball Test for Normal Consistency.—The ball test for determining the proper consistency is employed to a great extent in commercial laboratories where the Gilmore needles are used to determine the set. In spite of its crudeness the ball test gives results that agree fairly well with those determined by the Vicat apparatus. The ball test consists in forming the mortar into a ball and dropping it from a height of 1 foot. This fall should not materially flatten nor crack the ball; flattening would denote too much water in the mortar and cracking would indicate that there was not enough.

15. Moist Closet.—A convenient form of moist closet for use when only eight or twelve pats are to be tested at a time is shown in Fig. 4. It is made from an ordinary tin bread box, such as can be procured of any dealer in tinware. A removable shelf made of $\frac{1}{2}$-inch-mesh wire netting is held about midway between the top and bottom of the box by means of cleats and is stiffened by means of strips of folded tin. A wet sponge is placed in the bottom of the box and the pats are placed on the shelf. The box is to be kept closed, of course, except when applying the needles to the pats. Where many pats are tested a moist closet may be made by lining a wooden cupboard or clothes press of suitable size with tin. The shelves therein should slide in and out and a pan of water containing a large sponge should be placed in the closet

16. Influence of Temperature, Etc., on Setting Time.— The rate

Fig. 4

of set is influenced by a number of things chief of which are temperature and the percentage of water used in making the mortar. The higher the temperature the quicker the set, the larger the percentage of water the slower the set. Temperature has a very marked influence on the setting time, and many cements that are suitable for use in the United States could not be used in the tropics. Similarly in the early spring and late fall, when the temperature out of doors is from 20 to 30° F. below what it is indoors, cement that sets rather quickly in the laboratory may give perfect satisfaction when used outside. The percentage of water used to gauge the pats or, in actual work, to make the mortar, very greatly affects the
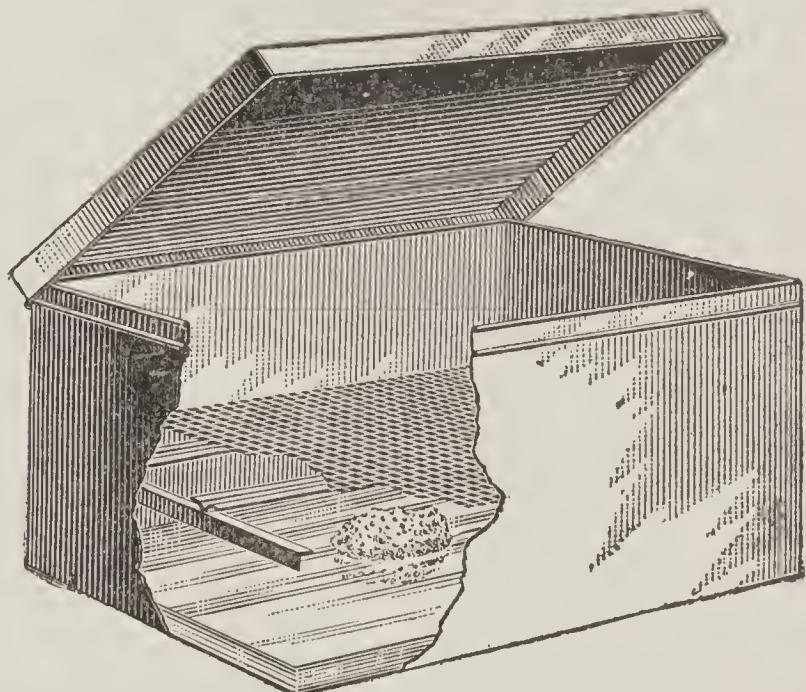
setting time as well as the early strength of the concrete. A wet mixture sets very slowly while a dry one sets much more promptly.

17. Addition of Retarders to Cement.—If Portland-cement clinker is ground just as it comes from the coolers without the addition of any foreign substance, the resulting cement is entirely too quick-setting to allow it to be worked properly. It is, therefore, the general practice either to grind a small percentage, usually 2 or 3 per cent., of gypsum with the clinker or to add to the cement just before it is shipped a corresponding percentage of finely ground plaster of Paris, in order to regulate the set so as to give time for working, tamping, and troweling. At some mills coarsely ground plaster of Paris, or calcined plaster, as the manufacturers call it, is added to the clinker before grinding.

Le Chatelier made many experiments on the effect of the addition of gypsum and plaster of Paris to Portland cement. He concluded that the governing action it exercised over the cement was due to the formation of certain soluble compounds between the sulphuric acid of the calcium sulphate and the very active calcium aluminates of the cement that cause quick-setting. He also stated that either gypsum or plaster of Paris could be added to retard the set.

Calcium chloride will retard the setting of cement although it had never been used for that purpose in mill practice. Candlot made many experiments to determine the effect of calcium chloride on the setting time of ground-cement clinker and found that from $\frac{1}{2}$ to 1 per cent. of calcium chloride was needed to produce the maximum effect. Beyond a certain point, however, addition of both plaster of Paris and calcium chloride make cement quick-setting again. Thus cement without any retarder set in 6 minutes; with 2 per cent. plaster of Paris added, it set in 6 hours, and with 5 per cent. plaster it set in 1 hour and 30 minutes. Gypsum, however, can be added to cement in any proportion without quickening its set.

Some cement is so quick-setting that it even sets under the trowel and on working gets dryer instead of more plastic. When

cement sets within a few minutes after water is mixed with it, it is said to have a *flash set*.

18.   Effect of Aeration on Setting Time.—Slow-setting Portland cement may become quick-setting on storage and quick-setting cement may season into slow-setting cement. Quick-setting cements, or cements that become quick-setting, are usually high in alumina and low in lime; consequently to remedy this defect it is necessary to increase the lime or to cut down the amount of alumina. Cement that is very much underburned is likely to be quick-setting but underburning is rarely ever the cause of quick-setting. Rapid cooling of the clinker helps to make cement slow-setting.

Where cement has become quick-setting from storage, it can generally be made slow-setting again either by adding from 1 to 2 per cent. of slaked or hydrated lime to it or by mixing the mortar with lime water. When cement becomes quick-setting from age, or long storage, it is customary to bring the setting time back to normal by adding plaster of Paris. Usually a certain quantity of plaster of Paris, as measured by means of a square box made to hold just so much when struck off level, is added to every barrow of cement as it is wheeled from the bin to the conveyer; or else a boxful of plaster of Paris is dumped into the conveyer at stated intervals of time. The screw conveyer then does the mixing. Quick-setting cements may also be made slow-setting by mixing them with slow-setting ones, but this must be done carefully to see that cement of both kinds is supplied in the desired proportions.

19.   Tensile Strength.—The tensile strength of cement is determined by using test pieces of cement mixed with sand molded in the form of briquettes. The smallest cross-section of these briquettes is 1 square inch in area. They are allowed to harden in air for 24 hours and are then kept in water and broken at stated intervals. Tensile tests of neat cement were at one time required and while not now specified are made as a matter of scientific record.

20.   Standard Sand for Briquettes.—The sand used to test the mortar strength of cement is the natural sand from Ottawa, Illinois. This sand is screened to pass a sieve having 20 meshes per linear inch and retained on a sieve having 30 meshes per linear inch, the wires to have diameters of .0165 and .011 inch, respectively; that is, half the width of the opening in
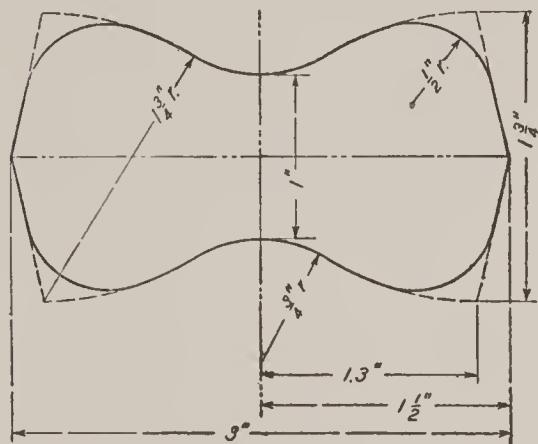

FIG. 5
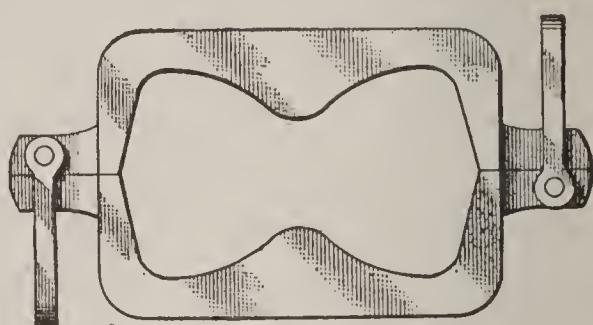
FIG. 6

each case. Sand having passed the 20-mesh sieve is considered as standard when not more than 1 per cent. passes a 30-mesh sieve after 1 minute of continuous sifting of a 500-gram sample. This sand may be obtained from the Ottawa Silica Company, Ottawa, Illinois.

21.   Form of Briquette.—The form of the present standard briquette is shown in Fig. 5. It differs from the old standard
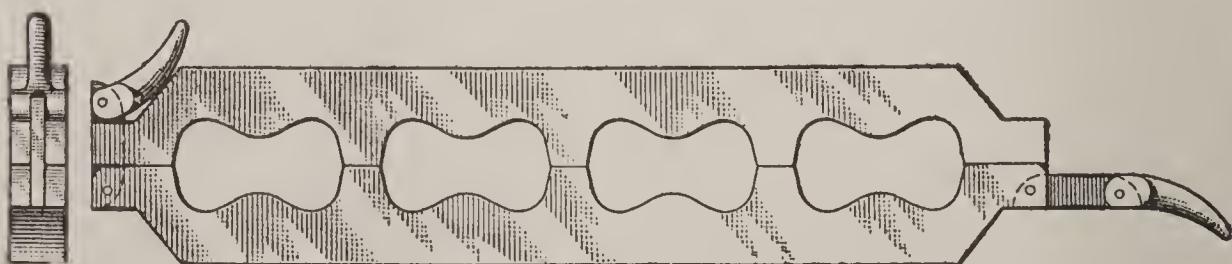

FIG. 7

form only in that the corners are rounded. For forming these briquettes, a single mold, Fig. 6, and a gang mold, Fig. 7, are used. The former gives slightly higher results, but the latter is more convenient because it permits a number of briquettes to be made at one time. The molds should be made of non-corrosive metal such as brass, bronze, or gun metal. After

being used the molds should be freed from caked cement by brushing them with a stiff scrubbing brush and scraping them with a piece of soft metal such as copper or zinc. After cleaning they should be wiped with an oily cloth and kept in a place free from dust.

22. Molding the Briquettes.—The first step in making the briquettes is to find out the quantity of water necessary to make a paste of normal consistency by the method previously outlined. This is the quantity of water to be used for neat briquettes. The proper quantity of water for sand mortar is then ascertained by referring to Table I. Next, the proper

TABLE I

PERCENTAGE OF WATER FOR STANDARD MORTARS

Percentage of Water for Neat Cement Paste of Normal Consistency	Percentage of Water for One Cement Three Standard Ottawa Sand*	Percentage of Water for Neat Cement Paste of Normal Consistency	Percentage of Water for One Cement Three Standard Ottawa Sand*
15	9.0	23	10.3
16	9.2	24	10.5
17	9.3	25	10.7
18	9.5	26	10.8
19	9.7	27	11.0
20	9.8	28	11.2
21	10.0	29	11.3
22	10.2	30	11.5

*Note.—The quantity of water is expressed in percentage of the combined weight of cement and sand. Thus, if 22 per cent. water is required for normal consistency, 102 cubic centimeters of water will be needed for a mixture of 250 grams of cement and 750 grams of sand.

quantities of cement and sand are weighed. For mortar briquettes the proportions are one of cement to three of sand and the combined weight of the two must lie between the limits of 500 and 1,000 grams. Usually 250 grams of cement and 750 grams of sand are employed. This weight will make

seven or with care eight briquettes. The two materials are then carefully mixed dry, the water added and the mixing done as already directed.

Having worked the paste or mortar to the proper consistency, it is at once placed in the molds, pressed in firmly with the thumbs and smoothed off with a trowel without ramming. The material should be heaped up on the upper surface of the mold, and in smoothing off, the trowel should be drawn over the mold in such a manner as to exert a moderate pressure on the excess material. The mold should be turned over and the operation repeated. Instead of kneading the cement mortar with the hands, as prescribed by the standard rules, most testers use a trowel, working the mortar back and forth on the table under the trowel until the desired plasticity is secured.

23. Breaking the Briquettes.—The briquettes are usually left in the molds over night, the molds and contents being placed in the moist closet or else covered with damp cloth. In the morning they are usually removed from the molds and kept in a moist closet for the balance of the 24 hours, after which they are placed in tanks and broken at intervals. The periods of breakage vary, but are usually 7 days, 28 days, 3 months, 6 months, 1 year, 2 years, and 5 years after making. When neat briquettes are made these are usually broken at the 24-hour period also, and these have, of course, never been placed in water. Nearly all cement testers make and break the 7-day and 28-day briquettes as required by the standard specifications, but some make no longer-period tests. The average tensile strength shown by at least three breaks or the strength of all the briquettes broken at each period is taken as the strength for that period. It should be noted, however, that where briquettes are manifestly faulty or give strengths differing by more than 15 per cent. from the average value of all briquettes from the same sample and broken at the same period, the result of the tests of these briquettes should not be included in the average. Sometimes five briquettes are broken for each period, this larger number giving a better average value for the tensile strength of the cement.

24. Briquette Tanks.—Where much testing has to be done a good form of trough for the storage of briquettes is made of stout 2-inch boards covered with sheet zinc. These troughs may be placed one above the other on a suitable wooden frame. A small stream of water should be kept running through them all the time. This can be done by arranging overflow tubes so that the water will flow from the upper trough into the next one below, etc. After the briquettes have attained their initial set and before being removed from the molds they should be marked with an identifying number and date by means of a marking brush and black paint or a black (carbon) grease pencil or crayon. Blue or other aniline pencil should not be used, as the alkali in the cement will discharge the color in time and render the marking invisible. Neat briquettes may also be marked by means of a steel die, when the marking should be done in the corners and never across the breaking section. Sand briquettes may also be marked by putting on a thin layer of neat cement, about 1/16 inch thick and marking this with a die. Where both neat and sand briquettes are made, frequently only the neat briquettes are marked and when these are placed in the tanks the neat briquettes are placed on top of the corresponding sand ones so as to make identification of the latter possible.

In storing the briquettes in the troughs it will be found most convenient to put all the briquettes to be broken in 7 days in order of breaking, in one part of the trough and those for 28 days in another. The briquettes may be placed edgewise in pairs, one on top of the other.

25. Briquette Testing Machines.—The best-known form of machine for breaking the briquettes is the Fairbanks automatic cement-testing machine, which is shown in Fig. 8. It consists of a cast-iron frame a made in one piece with a shot hopper b. To this frame are hung the two levers c and d. From the end of the upper lever d the weight is applied by allowing shot to flow from the hopper into the bucket f. The tension is applied to the briquettes held in the clips h by means of the lower lever c. The lower clip is attached by means of

a ball point to a screw with hand wheel p for lowering or raising it when putting in the briquettes and taking up the slack. There is also a counterbalance c for bringing the levers and bucket into partial equilibrium so that the final adjustment can be made with the ball l. The shot hopper is provided with a
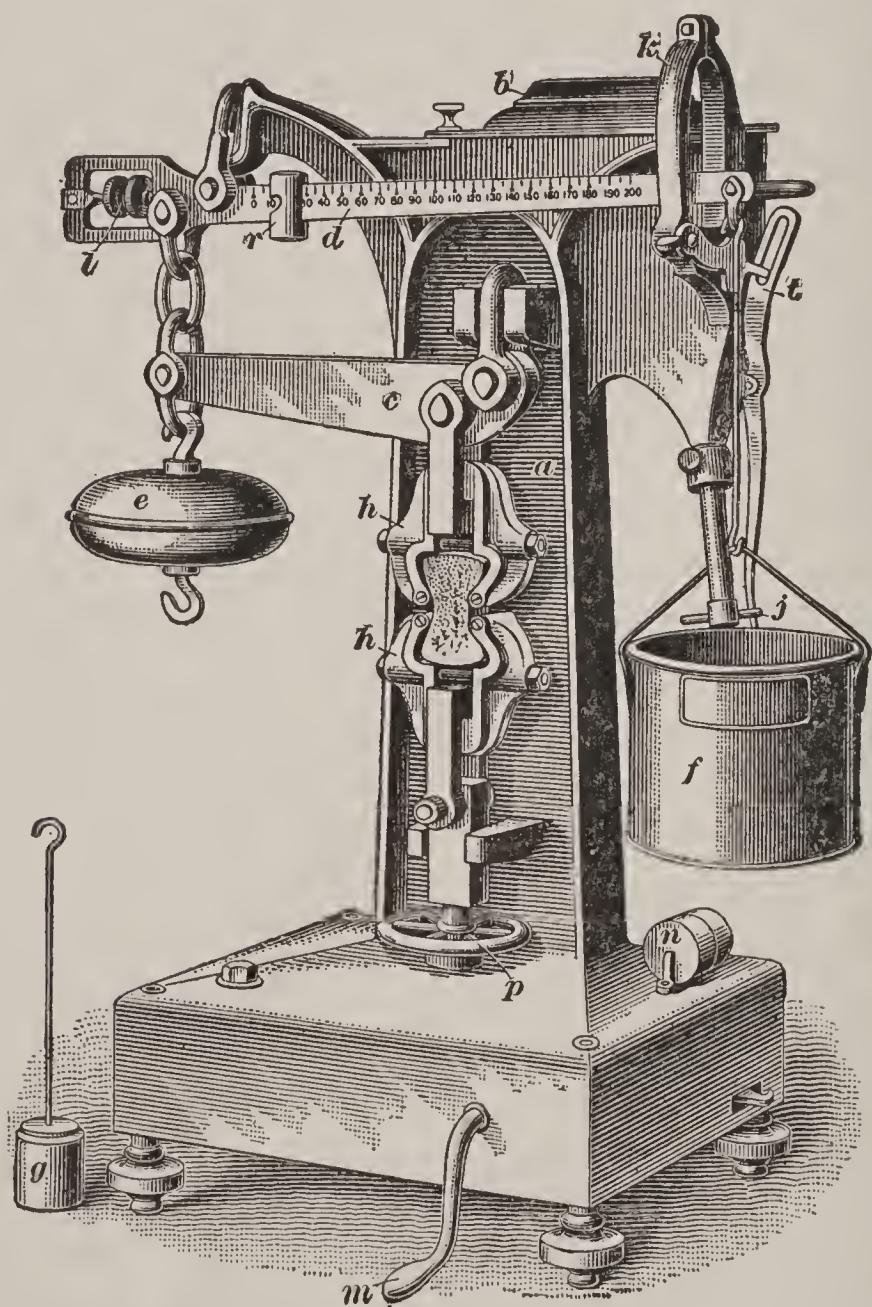

FIG. 8

lever t and gate j that cuts off the shot as soon as the specimen breaks. By hanging the bucket on the opposite end of the lever d the shot is weighed by means of a sliding poise r.

To operate the machine hang the bucket f on the end of the beam d as shown. See that the poise r is at the zero mark and

balance the beam by turning the ball l. Fill the hopper b with fine shot, place the specimen in the clamps h, and adjust the hand wheel p so that the graduated beam d will rise midway to the stop k. Open the automatic valve j to allow the shot to run slowly into cup f. As the shot drops into the bucket the graduated beam d will fall; tension should therefore be applied by turning the crank m to keep the beam d in mid-position. The shot is then allowed to run until the specimen breaks. When the specimen breaks the graduated beam d will drop and automatically close the valve j.

Remove the bucket with the shot in it and hang the counterpoise weight g in the place where the bucket was. Hang the bucket f on the hook under the large ball e and proceed to weigh the shot in the regular way, using the poise r on the graduated beam d and the weights n on the counterpoise weight g. The result will show the number of pounds required to break the specimen. The flow of shot, which can be regulated by the cut-off valve j, should be such that the quantity run into the bucket in 1 minute when balanced against the weights, is equivalent to 600 pounds. The briquettes should be broken as soon as removed from the water.

26. Soundness, or Constancy of Volume.—The soundness of cement is determined by making pat tests. Cement is mixed as for neat briquettes except that, generally, from 10 to 15 per cent. more water is used. After being thoroughly worked the mixture is placed on a glass plate about 4 inches square and made into a cake, or pat, that is about 3 inches in diameter, $\frac{1}{2}$ inch thick at the center, and drawn out to a thin edge at the circumference. In molding the pat, the cement is first flattened on the glass and the pat then formed by drawing the trowel from the outer edge toward the center. About 100 grams of cement is sufficient for a pat. As soon as made the pat is placed in a moist closet and allowed to remain there for 24 hours. It is then placed on a shelf in a loosely covered vessel of boiling water and steamed for 5 hours. The pats should be well above the water and the latter should be vigorously boiled. To pass the test the pats should be firm and hard

after the steaming or boiling and when small pieces of the edges are broken off between the thumb and forefinger they should break with a snap and not merely crumble between the fingers. The pat also should not show wedge-shaped radial cracks from the center. No attention need be paid to the pat coming off the glass, nor should a slight curvature, amounting to, say $\frac{1}{4}$ inch, provided the pat is sound and hard, be considered
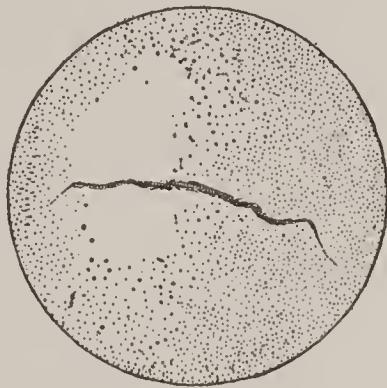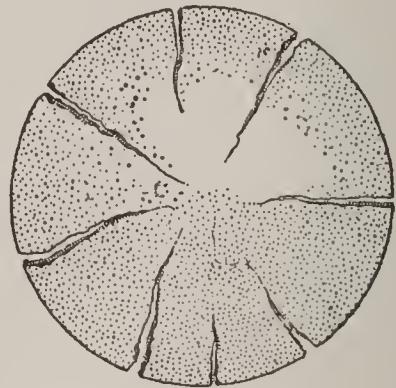
FIG. 9   FIG. 10

an indication of serious unsoundness. The heat alone may cause the glass to be cracked and broken, but since the coefficients of expansion of cement and glass are not the same something must give way, if the cement sticks to the glass; consequently as the glass is the weaker, it is usually the one to crack. The pats should remain on the glass, but their coming off is not an indication of unsoundness, provided they do not show extreme curvature or distortion.

Curvature can best be ascertained by placing a ruler across the bottom of the pat. Sometimes pats are made up too wet, in which case they are liable to crack on drying. These cracks can be readily distinguished from those due to unsoundness, as the latter always r a d i a t e from the

FIG. 11

center and are wedge-shaped, with the point of the wedge at the center, while the cracks due to drying are not wedge-shaped and do not radiate from the center. Fig. 9 shows a pat with drying cracks, and Fig. 10, one with the radial wedge-shaped cracks due to unsoundness. Fig. 11 shows a distorted pat and the method of detecting curvature.

27. Causes of Unsoundness.—Unsoundness is usually due to the presence of free lime in the cement. The presence of free lime may be due to several sources. The cement may be poorly proportioned and too much lime may be present to satisfy the acid elements silica and alumina, or the raw materials may be so coarsely ground that these elements cannot come into sufficiently close contact with each other to unite properly; finally, the temperature of burning may not have been high enough to bring about the combination. Often, too, cement that is unsound because it is coarsely ground would become sound with finer grinding.

Hydrated or slaked lime may be mixed with cement in all proportions and will not cause unsoundness. Calcium carbonate is also without effect on it and quicklime ground extremely fine also has no injurious action when mixed with cement, because when water is added to the mixture the lime promptly slakes. The free lime that does the damage, therefore, is that portion of it which is locked up in a kernel of clinker. The clinker forms a protecting casing over the free lime, and when the cement is made into mortar the water cannot get at the free lime to slake it until after the cement sets. In time, however, after the cement has hardened, the water breaks through the case of clinker and hydrates the free lime. Now, when lime slakes, expansion takes place; consequently, the particles of free lime swell with great force and crack the fully hardened concrete, just as water in freezing in an iron pipe will burst the pipe. By fine grinding, the coarse kernels of clinker in the cement are broken up, and water used in mixing the mortar can get at the lime to slake it before the cement sets.

28. Curing of Unsound Cement.—Unsound cement can usually be made sound by seasoning or storing it, when the moisture of the air will slake the free lime that is present. Unsound cement can also sometimes be made sound by the addition of from ½ to 1 per cent. plaster of Paris. It is a common error to suppose that an excess of plaster of Paris causes cement to expand and crack. Either plaster of Paris or gypsum may be added to cement in large proportions without causing

unsoundness. Magnesia is also supposed to cause expansion; cement may, however, contain 5 per cent. of this element without showing any ill effects from it.

CORRECTING FAULTY PORTLAND CEMENT

29. When cement fails to pass the required physical tests, the following remedies may be applied:

UNSOUNDNESS

1. Lower the percentage of lime in the raw material.
2. Burn the clinker harder.
3. Grind the raw materials finer.
4. Season the cement or clinker.
5. Add a little more gypsum or plaster of Paris.
6. Grind the cement itself finer.

QUICK SETTING

1. Raise the percentage of lime in the raw material.
2. Increase the amount of gypsum or plaster of Paris.
3. When it is possible to do so, replace some of the alumina of the mixture by ferric oxide or silica; that is, use a more silicious or ferruginous clay.
4. If unsound also, burn the clinker harder and season the cement.
5. Cool the clinker quickly with water.

LOW 7-DAY TENSILE STRENGTH

1. Increase the percentage of lime.
2. Increase the amount of alumina and decrease the amount of silica.
3. Increase the amount of gypsum slightly.

TOO HIGH 7-DAY TENSILE STRENGTH

If unsound, apply remedies given under Unsoundness
1. Decrease the percentage of lime.
2. Burn the clinker harder.
3. Grind the clinker coarser.
4. Add less gypsum or plaster.

5. Increase the amount of silica and decrease the amount of alumina.

6. Replace some of the alumina by iron oxide.

7. Season the cement.

Low Sand Strength

1. Grind the clinker finer.

2. Increase neat strength, if low, by methods outlined under Low 7-Day Tensile Strength.

Low Specific Gravity

1. Burn the clinker harder.

2. Do not store too long.

CHEMICAL ANALYSIS OF PORTLAND CEMENT AND RAW MATERIALS*

ANALYSIS OF PORTLAND CEMENT

30. The principles involved in the quantitative analysis of cement differ in no way from those laid down for other mineral analyses, but specialization being necessary in all lines of work it is natural that cement chemists should evolve methods peculiarly adapted to the material in hand. In cement laboratories it is necessary to arrive at fairly accurate results in a short space of time, and any method of yielding results accurate to .2 per cent. will serve the purpose, as two samples drawn from the same barrel and analyzed by the standard and more accurate methods will be found to vary that much.

Portland cement will be found to dissolve more or less completely on digestion with dilute hydrochloric acid, the completeness with which the cement dissolves depending on the care with which it has been made and the strength of the acid used to decompose it. A good, well-burned Portland cement will usually dissolve in dilute (1:3) hydrochloric acid without leaving a residue of more than .2 per cent. The scheme outlined

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*In connection with this Section, the student is referred to *Quantitative Analysis*, taking especial note of the precautions there given.

here has been gradually worked out in the laboratory and yields satisfactory results. Before submitting the cement to a chemical analysis, it should be passed through a 100-mesh test sieve to free it from pieces of clinker too large to be attacked quickly by the acid.

31. Determination of Silica.—Weigh .5 gram of cement into a wide platinum or porcelain dish. The former is the more expensive of the two, but it is a better conductor of heat, and there is no danger of the solution becoming contaminated with silica, etc. from the dish. Now stir up the sample of cement in the dish with 10 cubic centimeters of cold water until all lumps are broken, and add immediately 10 cubic centimeters of cold dilute (1:1) hydrochloric acid. Place the dish on a water bath and evaporate to dryness, stirring occasionally. The water bath will evaporate as fast as anything else and there is no danger of the silica spattering, which it is liable to do when a hot plate is used, unless the operation is very carefully watched. As soon as the contents of the dish is dry place it in an air bath and dry at 100° to 110° C. for 1 hour. Cool, add 10 cubic centimeters of dilute hydrochloric acid and 20 cubic centimeters of water to the contents of the dish, cover with a watch glass and digest on the hot plate for 5 or 10 minutes. Filter off the silica on a 9-centimeter filter, wash from seven to ten times with hot water, put in a weighed platinum crucible, ignite over the Bunsen burner until all the filter paper is consumed, and then ignite strongly over a blast lamp for 10 minutes. Cool in a desiccator and weigh as SiO_2; multiply the weight by 200 for percentage of silica, SiO_2.

32. Determination of Iron and Alumina.—Heat the filtrate to boiling and add a small but distinct excess of ammonia. This can be most conveniently done by means of a bottle fitted with a siphon tube the end of which terminates in a jet connected to it by a short piece of rubber tubing, which is closed by a pinch cock, as shown in Fig. 12. The bottle stands on a shelf over the reagent table and the siphon extends to within 6 inches of the surface of the table. The beaker is placed under the jet and the ammonia can be added very care-

fully and conveniently by pressing the pinch cock. After adding the ammonia, replace the beaker on the hot plate and boil for 5 minutes. Remove from the hot plate and allow the precipitate to settle. Filter on an 11-centimeter filter paper and wash once with hot water to collect the precipitate in the cone of the filter. Invert the funnel over the beaker in which the precipitation was made and wash practically all of the precipitate back into the beaker, allowing the filter paper to remain in the funnel. Dissolve the precipitate in 20 cubic centimeters of 1:5 nitric acid and dilute the solution to 100 cubic centimeters. Heat to boiling and reprecipitate with ammonia as before. Boil for 5 minutes, allow the precipitate to settle, and filter through the same filter paper as used for the first precipitate. Wash once with hot water, ignite carefully in a weighed crucible over a Bunsen burner, and finally with the blast lamp for 5 minutes. Cool and weigh as combined oxides of iron and aluminum $Fe_2O_3 + Al_2O_3$. This precipitate also contains phosphoric, P_2O_5, and titanic, TiO_2, acids, both of which are present in small quantities in cement.
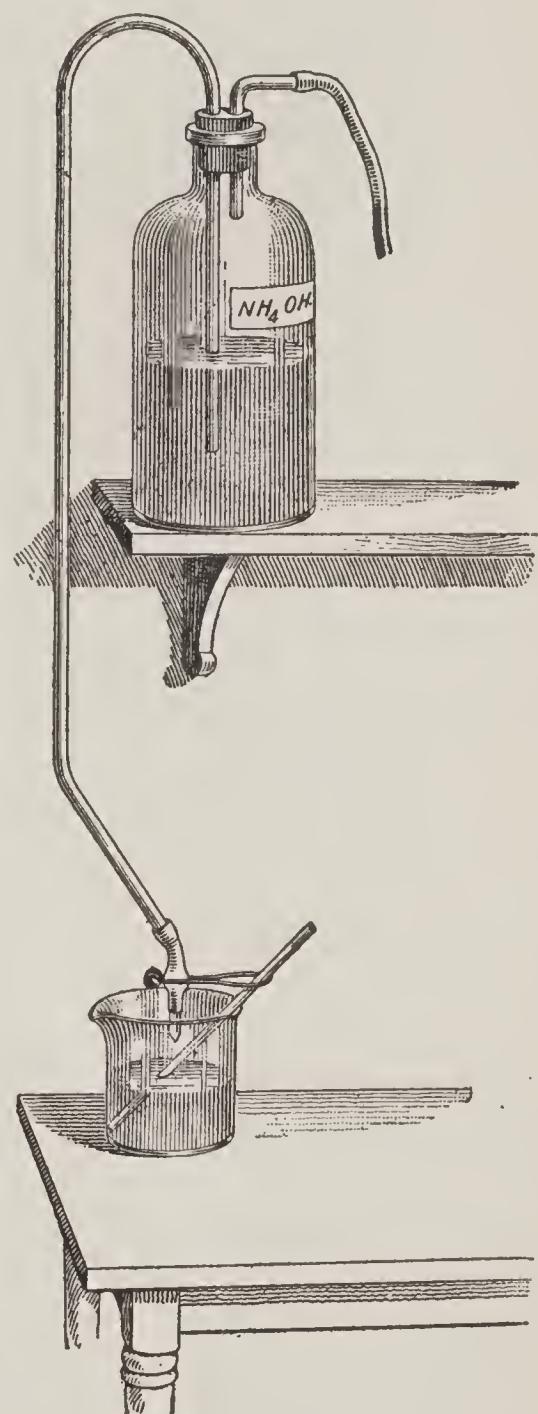

Fig. 12

33. Determination of Lime.—Make the filtrate from the iron and alumina alkaline with ammonia; boil, and add 20 cubic centimeters of boiling saturated ammonium-oxalate solution, or, better, 2 grams of solid ammonium-oxalate dissolved in from 25 to 50 cubic centimeters of boiling water.

just prior to use. This may be measured instead of weighed with a small marked test tube. Stir well, allow 15 minutes to settle, filter on an 11-centimeter filter and wash ten times with hot water, using as little as possible, about 100 to 125 cubic centimeters to do the work well. · Transfer the paper and precipitate to the beaker in which the latter was formed, and open the paper and spread it out against the upper side of the beaker. Wash the precipitate off the paper with a jet of hot water, hold the paper over and allow it to remain against the walls of the beaker; add 50 cubic centimeters of dilute (1 : 4) sulphuric acid, dilute to 150 cubic centimeters, and heat until the solution is between 60° and 90° C. Titrate with permanganate solution until a pink color is produced. All this time the paper should be sticking to the wall of the beaker. Now drop the filter paper into the solution and stir. The pink color of the latter will be discharged. Finish the titration very carefully by adding a drop of permanganate at a time and calculate the lime, CaO.

34. Determination of Magnesia.—If the filtrate from the lime measures over 250 cubic centimeters, acidify and evaporate until this bulk is reached. This can be rapidly done by using a large, say 8-inch, porcelain dish in the following manner: Place a piece of wire gauze on a tripod, and in the center place a piece of thin asbestos paper about the size of a silver dollar. Now place the dish on this and place a Bunsen burner turned fairly low under the dish. The contents of the dish can then be made to evaporate rapidly without boiling by regulating the flame. When the solution measures 250 cubic centimeters transfer to a beaker, cool and when cold add 15 cubic centimeters of a 10-per-cent. solution of sodium phosphate and 15 cubic centimeters of strong ammonia. Stir thoroughly and set aside in a cool place for at least 6 hours. Filter, wash with a solution made by mixing 800 cubic centimeters of water with 300 cubic centimeters of concentrated ammonia (specific gravity .96) and 100 grams of ammonium nitrate. Place in a weighed platinum or porcelain crucible and ignite over a low flame until all the carbon is burned off. (Do not

use the blast lamp.)   Cool in a desiccator and weigh as magnesium pyrophosphate, $Mg_2P_2O_7$.   The weight multiplied by .3619 gives the weight of magnesia, MgO; to get the percentage of MgO in the sample, multiply by .7238.

35.   Preparing and Standardizing the Permanganate.—The most convenient strength for the permanganate is 5.64 grams of the salt to a liter of water.   One cubic centimeter of this solution will then be equivalent to about 1 per cent. of lime where a .5-gram sample is used.   To standardize the permanganate weigh into a 400-cubic-centimeter beaker .67 gram of sodium oxalate, which has been especially prepared for use as a volumetric standard.   Dissolve in 100 cubic centimeters of water and when all is in solution add 10 cubic centimeters of dilute (1 : 1) sulphuric acid.   Heat to 60° C. and titrate with the permanganate.   The above quantity of sodium oxalate is equivalent to .5 gram of calcium carbonate or .28 gram of calcium oxide.   The value of the permanganate solution is found by dividing 28 by the number of cubic centimeters of permanganate required by .67 gram of sodium oxalate.

36.   Determination of Iron Oxide.—Weigh 1 gram of finely ground cement into a small beaker and add 15 cubic centimeters of dilute hydrochloric acid, heat from 10 to 15 minutes and add a little water.   Heat to boiling and filter through a small filter, washing the residue well with water and catching the filtrate and washings in a porcelain dish.   Add to the solution 5 cubic centimeters of dilute hydrochloric acid and bring to a boil.   Add carefully drop by drop stannous-chloride solution (35 grams in 100 cubic centimeters of dilute 1 : 3 hydrochloric acid) until the last drop makes the solution colorless.   Remove from the burner and cool the liquid by setting the beaker in a vessel of cold water.   When nearly cold, add 15 cubic centimeters of saturated mercuric-chloride solution and stir the liquid in the dish with a glass rod.   Allow the mixture to stand for a few minutes during which time a slight white precipitate should form.   Run in standard bichromate solution carefully from a burette until a drop of the iron

solution tested with a drop of 1-per-cent. solution of potassium ferricyanide no longer shows a blue color, but, instead, a yellow color. Multiply the number of cubic centimeters of bichromate used by the ferric-oxide equivalent per cubic centimeter of the bichromate and divide the product by the weight of the sample. The result, multiplied by 100, gives the per cent. of the ferric oxide, Fe_2O_3, in the cement.

The most convenient strength for the standard bichromate solution is 3.074 grams of the salt to the liter. One cubic centimeter of this solution is equivalent to .005 gram of ferric oxide. It should be standardized against iron wire or ferrous ammonium sulphate.

37. Determination of Sulphuric Acid.—Weigh 1 gram of the sample into a small dry beaker and stir it up with 10 cubic centimeters of cold water until all lumps are broken up and the lighter particles are in suspension. Add 15 cubic centimeters of dilute (1:1) hydrochloric acid and heat until the solution is completed. Filter through a small paper and wash the residue thoroughly. Dilute the filtrate to 250 cubic centimeters, heat to boiling, and add 10 cubic centimeters of boiling 10-per-cent. barium-chloride solution. Stir well and allow to stand over night. Filter, ignite, and weigh as $BaSO_4$, which weight multiplied by .34297 gives the weight of SO_3.

38. Loss of Ignition.—Weigh .5 gram of cement into a weighed platinum crucible, cover with a lid, and heat for 5 minutes over a Bunsen burner, starting with a low flame and gradually raising it to its full height. Then heat for 15 minutes over a blast lamp. Cool and weigh. The loss of weight represents the loss on ignition. This loss consists mainly of combined water and carbon dioxide driven off by the heat. Some chemists report, therefore, as carbon dioxide and water, or, having found the carbon dioxide, subtract the percentage from that of the loss on ignition and call the remainder water of combination, or combined water.

Of the other elements in cement the alkalies are occasionally determined. The method for doing this is similar to that used for determining potash and soda in minerals, etc.

39.   Rapid Determination of Lime (Meade's Method).—It is often useful to know the percentage of lime in cement as a check on the composition of the raw material. The following method gives quick and very accurate results:

Weigh .5 gram of cement into a dry 500-cubic-centimeter beaker and add with constant stirring 20 cubic centimeters of cold water. Break up the lumps and when all the sample except the heavier particles is in suspension, add 20 cubic centimeters of dilute (1 : 1) hydrochloric acid and heat until the solution is completed. This usually takes 5 or 6 minutes. Heat to boiling and add carefully to the solution dilute ammonia (96 specific gravity) until a slight permanent precipitate forms. Heat to boiling and add 10 cubic centimeters of a solution of oxalic acid (100 grams to the liter). Stir until the oxides of iron and aluminium are entirely dissolved and only a slight precipitate of calcium oxalate remains. Add 200 cubic centimeters of boiling water and sufficient saturated solution of ammonium oxalate, say 20 cubic centimeters, to precipitate the lime. Boil and stir for a few moments, remove from the heat, allow the precipitate to settle, and filter on an 11-centimeter filter. Wash the precipitate and paper ten times with hot water, using not more than 10 to 15 cubic centimeters of water each time. Remove the filter from the funnel, open and lay against the sides of the beaker in which the precipitation was made, wash from the paper into the beaker with hot water, add dilute sulphuric acid, fold the paper over, and allow to remain against the walls of the beaker. Heat to 80° C. and titrate with standard permanganate until a pink color is obtained; now drop in the filter paper, stir until the color is discharged and finish the titration carefully drop by drop.

40.   Insoluble Residue.—Weigh 1 gram of cement into a beaker and stir up with 10 cubic centimeters of water. Add 5 cubic centimeters of concentrated hydrochloric acid, and warm until effervescence ceases. Dilute the liquid to 50 cubic centimeters and heat until all soluble matter is in solution and only white flakes remain. Filter on a 9-centimeter filter, wash with cold water then drop the filter paper into the beaker in

which solution was effected. Pour 30 cubic centimeters of a 5-per-cent. sodium carbonate solution into the latter, and digest the filter with the sodium carbonate solution for 15 minutes at a temperature just short of boiling. Filter the residue and old filter on a new filter, wash with cold water several times, then with hot hydrochloric acid (1 : 9) and finally with hot water. Ignite at a red heat and weigh as insoluble residue.

ANALYZING AND PROSPECTING THE RAW MATERIALS

41. Before locating a mill at any point, it is important to determine accurately the quantity and quality of the raw materials that it is desired to use.

42. Limestone and Cement Rock.—In prospecting deposits of limestone and cement rock they should be sampled by means of a core or churn drill, and the test holes should be sunk to a considerable depth. Surface samples knocked off here and there are of little value, and the time spent in analyzing any number of them is in most cases thrown away. In sampling limestone or other solid material the surface dirt and clay should be shoveled away and the weathered rock removed. The drill can then be set up and the sample taken. In prospecting a limestone property it is customary to make a map showing the topography, etc., and this should be divided into squares having sides of, say, 25, 50, or 100 feet. Drill holes can then be sunk at the corners of each square, and the cores or chips brought up by the drill can be saved for analysis. Usually it is the custom instead of making one sample of all the rock brought up by the drill from a hole, to make separate samples of the material brought up from various depths. Thus, one sample would represent the material brought up from a hole from 5 to 10 feet deep, while the next would represent that taken by the drill in going from 10 to 15 feet, etc. In this manner, the uniformity of the deposit as well as its freedom from bands of magnesian stone, etc., can be tested.

43. Clay.—Clay may be sampled in a number of ways, such as by digging pits or by sinking test holes by means

of an auger drill or a serrated pipe; that is, a pipe filed on the lower end so as to form sharp teeth like those of a saw. Hard clays and shales will require either the auger or the churn drill. The serrated pipe is forced down into the clay by twisting a handle at the upper end. The result when withdrawn is a plug of clay which fills the pipe and represents the strata through which the pipe has passed.

44.   Marl.—For sampling marl, a tube similar to that used in sampling cement or the serrated pipe already described may be used. If the marl deposit is very wet, a long pipe having a plug at one end will be found serviceable. This plug should be of iron and have a sharp point. It should fit the mouth of the pipe closely and be fastened to a long, thin, iron rod. In using the sampler the iron plug is drawn up against the mouth of the pipe and the pipe is shoved down to the depth at which the sample is to be taken. The pipe is then raised and shoved down to its former level, being forced tight against the iron plug. The pipe is then raised by means of the rod and the sample dumped out. Marl deposits should be carefully mapped out in order that the quantity available may be calculated, as this is often an important consideration.

45.   Calculating the Amount of Material Available.—Before locating a cement plant at any point, the promoters should make sure that the deposit is extensive enough to furnish the raw material for many years. The first step is to map out the supply, and, if possible, determine its depth. The number of tons present can then be calculated from the data given in Table II.

Since, on an average 610 pounds of mixed raw material will be required to produce one barrel of cement, the calculation of the amount of cement that can be made from the deposit as mapped out is then simple, and can best be explained by an example: Let it be supposed that the area of a prospected marl deposit is 1,987,600 square feet, and that its average depth is 31 feet. The average composition of the marl is 95 per cent. calcium carbonate and of the clay to be mixed with it is 5 per cent. calcium carbonate. Now, the proportions of clay and marl will

TABLE II

WEIGHT OF VARIOUS RAW MATERIALS FOR PORTLAND-CEMENT MANUFACTURE

Raw Material	Weight in Pounds per Cubic Foot	Weight in Pounds per Cubic Yard
Limestone............	160	4,320
Cement rock..........	156	4,212
Marl (wet)...........	48	1,296
Clay.................	120	3,240
Shale................	160	4,320

be 20 : 70. Then, $\frac{70}{90} \times 610$, or about 475 pounds of marl, will be required to make a barrel of cement. One cubic foot of marl weighs 48 pounds; therefore, the marl deposit will contain $1,987,600 \times 31 \times 48 = 2,957,548,800$ pounds, and since 475 pounds of marl is required to make a barrel of cement, the marl deposit is sufficient for $2,957,548,800 \div 475 = 6,226,418$ barrels.

46. Methods of Analysis.—Methods of analysis for limestone, clay, and blast-furnace slag have all been given in *Quantitative Analysis*. The scheme detailed is the best for the analysis of cement rock and limestones. The samples should, of course, be thoroughly dried at 100° to 110° C. before being analyzed, and can best be preserved in small ½-ounce, wide-mouth bottles.

47. Analysis of Cement Rock.—Weigh .5 gram of finely ground dried sample into a platinum crucible and mix intimately with .5 gram of pure, dry sodium carbonate by stirring with a glass rod. Place the crucible over a low flame and gradually raise the flame until the crucible is red hot. Continue heating for 5 minutes; then substitute a blast lamp for the Bunsen burner and heat for 5 minutes longer. Place the crucible in a dish or casserole, add 40 cubic centimeters of water and 10

cubic centimeters of hydrochloric acid, and digest until the mass is dissolved out of the crucible. Clean off the crucible inside and outside add a few drops of nitric acid to the solution and evaporate it to dryness. Heat the residue at 110° C. for 1 hour, cool, add 15 cubic centimeters of dilute hydrochloric acid, cover with a watch glass, and digest for a few minutes on the hot plate. Dilute with 50 cubic centimeters of hot water, heat nearly to boiling, and filter. Wash the precipitate with hot water, ignite, and weigh as silica. Determine the iron and alumina, lime, magnesia, and loss on ignition as described for cement (see Arts. **32, 33, 34, 38**). To determine sulphur proceed as in determining this constituent in minerals or iron ores.

ANALYSIS OF CEMENT MIXTURES, SLURRY, ETC.

48. Since the success of cement-making depends primarily on the proper proportion of calcium carbonate to silica and alumina in the mixture, it is highly important to be able to estimate this ratio quickly. If the materials from which the mixture is made are of normal constitution, a determination of the calcium carbonate alone will suffice to check the correctness of the mixture. For rapidly checking the percentage of calcium carbonate, the alkalimetric method, in which the calcium carbonate is decomposed by a measured quantity of standard nitric or hydrochloric acid, and the excess of acid determined by titration with standard alkali, is most frequently used in the United States. This method does not give very accurate results, however, and when the exact composition of the mixture is desired, resort must be had to the gravimetric methods already outlined. When the slurry of the wet process is analyzed, it should first be evaporated to dryness, then finely pulverized in a mortar, and again dried for half an hour at 110° C. It will then be free from moisture and ready for analysis.

49. Sampling of Dry Mixtures.—For the control of the composition of the mixture of raw materials, it is customary to take samples at certain places during the grinding. In the dry process, this is usually done either after the material leaves

the ball mills, if these are used to do the grinding, or after it leaves the Griffin mills, if they are employed for this work. When tube mills follow the ball mill it is the custom to check the composition of the raw material further after it leaves these mills. The sample taken from any of the sources just mentioned will need further grinding, but, as a rule, it is not dried unless a complete analysis is to be made. Since the rapid scheme about to be given is affected by the fineness to which the sample is ground, it should be prepared the same way each time by passing all of it through a 100-mesh test sleeve.

50. Sampling of Slurry.—In the wet process the analytical methods are the same as in the dry process, but the sample itself usually has to be freed from a large amount of water (from 50 to 60 per cent.) by evaporation and drying. The slurry samples are usually taken from the mixing pits, and also after the slurry has passed through the tube mills, either from the discharge of the mill itself or from the ground-slurry pits. In sampling from the mixing pits a common, narrow quart pail fastened to the end of a wooden pole by means of a harness snap will be found convenient. The pail is put in the slurry bottom side up, pushed down to the required depth, and then drawn up. As the pole is lifted the pail turns over, fills with slurry, and may be lifted out. The vat is usually sampled at three or four depths, these samples are mixed, and from the mixture a small sample is drawn for testing. The slurry sample is usually spread on a sheet of cardboard and dried rapidly on a hot plate, after which it is powdered for the analysis.

51. Checking the Composition of the Mixture.—In order to check the composition of the mixture, the following solutions should be prepared: (1) Phenol-phthalein indicator; (2) $\frac{2}{5}$ N sodium hydroxide of exact strength; and (3) Hydrochloric acid approximately $\frac{2}{5}$ N.

One cubic centimeter of the alkali is equivalent to .02 gram of calcium carbonate, or 2 per cent. in the mixture if a 1-gram sample is used for the titration. After this, prepare a standard sample of the mixed raw material as this is necessary in order to standardize the acid for actual use. By *standard*

sample is meant a sample of the mixture whose composition has been accurately determined. It should all be ground to pass a 100-mesh sieve and dried at 100° to 110° C. After drying the sample should be carefully analyzed. This sample should contain approximately the quantity of calcium carbonate that it is desired to have in the mixture, and the amount of . magnesia should also be normal. When the magnesia varies at different times, fresh standard samples should be prepared to contain these varying percentages of magnesia; otherwise, the lime will be reported too high or too low.

52. Method of Standardizing the Acid.—Weigh 1 gram of the standard sample into a 600-cubic-centimeter Erlenmeyer flask and run in from a pipette 50 cubic centimeters of standard acid. Close the flask with a rubber stopper having inserted through it a glass tube about 30 inches long and about $\frac{3}{8}$-inch internal diameter. Heat the flask on a wire gauze over a burner, as shown in Fig. 13, until steam just begins to escape from the upper end of the tube. The

FIG. 13

heating should be so regulated that the operation will require very nearly 2 minutes from the time the heat is applied until steam issues from the tube. Remove the flask from the heat as soon as the steam escapes from the tube, and rinse the tube into the flask in the following manner: Rest the flask, still stoppered, on the table and grasp the tube between the thumb and the forefinger of the left hand. From a wash bottle in the
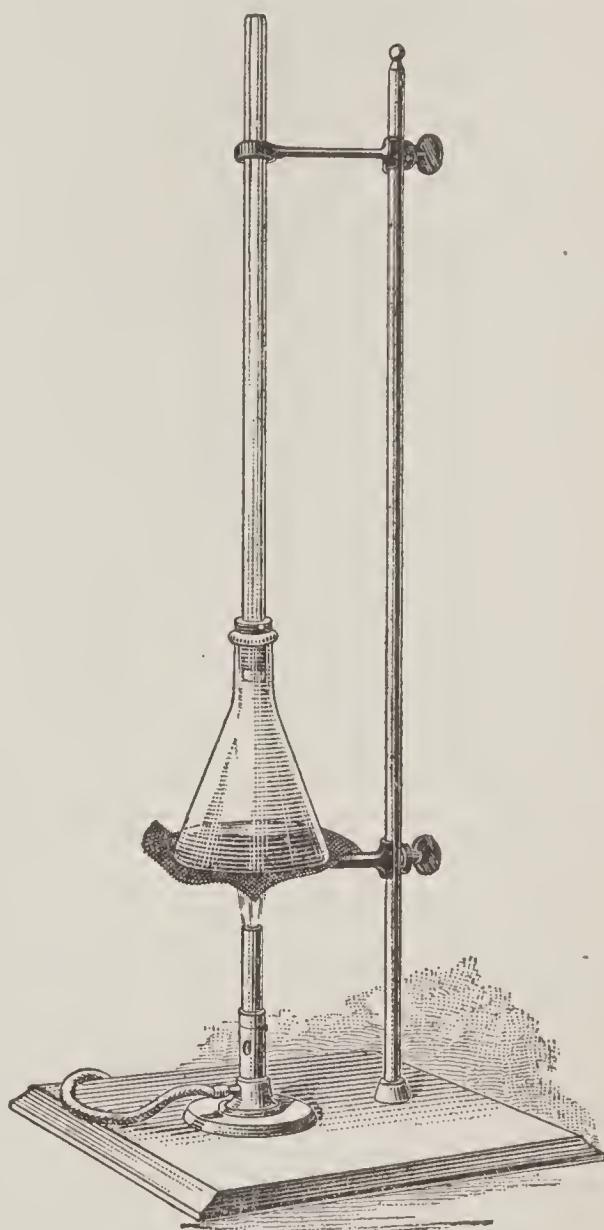
right hand direct a stream of cold water down the tube, holding the latter inclined at an angle of 45°, and rolling the flask from side to side on the table, in sweeps of 2 or 3 feet, by twirling the tube between the finger and thumb. Unstopper the flask, thoroughly rinse off the sides and bottom of the stopper into the flask, and wash down the sides of the latter. Add a drop or two of phenol-phthalein indicator and run in the standard alkali from a burette until the color changes to purple red. This color is often obscured until the organic matter settles; it is therefore necessary to hold the flask to the light and observe the change by glancing across the surface. A little practice will enable the operator to carry on the titration with accuracy and precision.

53. If the standard sample contains L per cent. calcium carbonate, and d cubic centimeters of alkali is required to produce the purple-red color, then to find the calcium carbonate in other samples, it is simply necessary to subtract the number of cubic centimeters of alkali required by these samples from d, multiply the difference by 2, and add to L for the percentage of calcium carbonate in them; or if the number of cubic centimeters is greater than d, subtract d from this number, multiply by 2, and subtract from L for the calcium carbonate.

54. The method described in Art. **39** may also be modified and used to check the acid and alkali determinations, as it gives very accurate results. To use this method mix .5 gram of the raw material with .25 gram of finely ground sodium carbonate by stirring with a glass rod. Brush off the rod into the crucible and ignite over a Bunsen burner, starting with a low flame and gradually raising it until the full heat is attained. Continue heating for 5 minutes longer and then ignite over the blast for the same length of time. Place the crucible in a 500-cubic-centimeter beaker and decompose the sintered mass in the crucible with 40 cubic centimeters dilute (1 :3) hydrochloric acid, keeping the beaker covered with a watch glass, to avoid loss by effervescence. Heat until the mass is completely dissolved, and proceed exactly as in Art. **39** by adding ammonia in slight excess, etc.

INSPECTION OF CEMENT

55. It is now the custom to inspect carefully all cement to be used in the construction of important government and municipal works. The large railroads and careful engineers and architects also require that the cement they purchase shall be tested and meet their specifications. The method of inspection differs somewhat with the character and extent of the work to be done. Cement is inspected in three ways, as follows: (1) The usual plan is to take a sample from the car as it is received at the warehouse of the contractor, and to pile the contents of each car where it can be identified, usually in stalls or bins. The sample is then subjected to the usual physical tests and the contractor is notified whether or not the cement is all right and may be used. (2) The sample of cement may also be drawn by the inspector at the mill when the car is packed. The sample is then forwarded to the laboratory for test. Usually much time can be saved by this method. (3) Instead of inspecting the cement in the cars, the cement in the bins at the mill may be sampled and tested and the cars then packed from the bins containing the cement that has been tested and accepted. This plan saves the trouble of storing large quantities of cement at the point of use.

The first method is the one most commonly used, but the least satisfactory of the three, as it makes the contractor provide large storage sheds for the cement, and, should the latter prove unsatisfactory, the cement must in some cases be reloaded on the cars and shipped back to the mill. The second method has few advantages over the first except the saving of time. The third method is the best of the three but is suited only to inspecting large quantities of cement. If the first method of inspection is followed, the testing laboratory is usually located at or near the work for which the cement is to be used. If either of the other plans is followed the laboratory is located at the cement mill when only one brand of cement is being used, or at some central and easily accessible point when the cement is purchased of several companies.

56.   Sampling Bins of Cement.—In sampling cement that is stored in bins, the most convenient form of sampler is a long piece of 1-inch iron or brass pipe in which slots $\frac{1}{2}$ in. $\times$ 18 in. are cut.   The edges of the slots should be sharpened, and one of them should be turned slightly outward, so that when the pipe is revolved in the bin the cement will be scraped into the tube.   The pipe end is fitted with a sharp, steel point.   In sampling the cement, the pipe is thrust down to the bottom of the bin, using a heavy wooden mallet if necessary, and then turned round two or three times in the proper direction to fill it. It is then withdrawn, turned upside down, and the cement shaken out into a bag by tapping the end of the pipe against the side of the bin or running a wire in through the slots.

57.   In inspecting cement tests are usually made to determine fineness, initial and final setting time, soundness and tensile strength with sand (7 days and 28 days).   Chemical analyses are also occasionally made to check the percentages of magnesia and sulphur trioxide.

CHEMICAL SUPERVISION OF THE PROCESS OF MANUFACTURING PORTLAND CEMENT

58.   The routine work of the chemist at a Portland-cement mill is about as follows:

1.   Samples of the raw materials are usually taken in the dry process from the mixed drill holes of every blast, and in the wet process from every pitful of marl and from every bin of clay. These samples are analyzed, sometimes completely and again only for calcium carbonate; and, if marl and clay, for the percentage of water they contain.   The raw materials are then mixed in proper proportions according to the results of these analyses.

2.   Samples of the dry mixture are taken every few hours from the ball mills if these are used to do the grinding, or from Griffin mills if they are employed, and the calcium carbonate in the samples is rapidly determined.   The results of these deter-

minations are used as a check on the mixture. If the results show the mixture to be too high or too low in lime, it is of course too late to do anything with the material already ground, and the efforts of the chemist must be directed toward making the subsequent mixture of proper composition by immediately correcting the proportions of the raw materials. The correction necessary can be calculated from the result of the check. In some plants using ball and tube mills samples are also taken from the tube mills as a further check on the composition of the mixture. In the wet process the slurry is sampled either before or after it comes from the tube mills, and if not of correct composition clay is stirred in until the mixture contains the proper proportion of calcium carbonate.

3. Samples of the fully ground raw materials are tested for fineness on a 100-mesh sieve once a day or oftener, and if not ground fine enough the mills are adjusted so that the next lot will not be so coarse. Sometimes the product of each mill is tested regularly in order better to correct the trouble; and, again, only the average sample is tested. If the latter is found to be too coarse, however, it is necessary to test each mill in order to find out with which one the trouble lies.

4. The clinker is carefully examined two or three times a day to make sure that the burning is done properly.

5. The ground cement is tested for fineness, setting time, soundness, tensile strength (neat and with sand), and chemical composition. The mills individually or collectively are tested for fineness at least once a day and usually oftener. The cement is tested for soundness and setting time at least once a day, but it is customary to make tensile-strength tests, chemical analyses, etc., of the cement in bins only as they are filled, or, where the bins are small, of the cement in a group of two or more bins filled consecutively. The cement in such bins or groups of bins is also tested for setting time, soundness, and fineness, and a statement called a *test sheet,* giving the results of all these tests, is sent out with each car of cement packed from the tested bins. When the cement in the bins is unsound it should be seasoned, samples being drawn now and then to determine when the free lime is all slaked and the cement can be packed.

ANALYSIS AND TESTING OF LIME

59. Methods of Analysis.—Lime is best analyzed by the scheme given for cement in Arts. **31** to **38**, inclusive. Lime is graded by analysis, and the usual classification followed is that of the committee of the American Society for Testing Materials, as follows:

(a) *Selected*.—Well burned, picked free from ashes, core, clinker, or other foreign material.

(b) *Run-of-Kiln*.—Well burned, without selection.

Quicklime is shipped in two forms:

(a) *Lump Lime*.—Kiln size.

(b) *Pulverized Lime*.—Reduced in size to pass a $\frac{1}{4}$-inch screen.

Quicklimes are divided according to their chemical composition into four types: (a) High calcium; (b) calcium; (c) magnesium; (d) high magnesium.

The following chemical limits are used to classify the various kinds of lime:

TABLE III
CHEMICAL COMPOSITION

	Calcium		High-Calcium		Magnesian		High-Magnesian	
	Selected Per cent.	Run-of-Kiln Per cent.	Selected Per cent.	Run-of-Kiln Per cent.	Selected Per cent.	Run-of-Kiln Per cent.	Selected Per cent.	Run-of-Kiln Per cent.
Calcium Oxide...	85–90	85–90	90 (min.)	90 (min.)	......	......	......	......
Magnesium Oxide	......	......	......	......	10–25	10–25	25 (min.)	25 (min.)
Calcium Oxide + Magnesium Oxide............	90	85	90	85	90	85	90	85
Carbon Dioxide (max.).........	3	5	3	5	3	5	3	5
Silica+Alumina+ Oxide of Iron (max.)........	5	7.5	5	7.5	5	7.5	5	7.5

NOTE.—Hydrated lime takes the same chemical classification as the lime from which it was made.

60.   Testing of Lime.—The tests usually applied to lime are those for the sand-carrying capacity and for the percentage of waste.   Hydrated lime is tested for sand-carrying capacity, for fineness, and for soundness.

Quicklime is shipped in bulk and the sample must be taken so that it will represent an average of all parts of the shipment from top to bottom, and not contain a disproportionate share of the top and bottom layers, which are most subject to changes due to absorption of carbon dioxide and water from the air. The samples should comprise at least 10 shovelfuls from different parts of the shipment.   The total sample taken should weigh at least 100 pounds and should be crushed to pass a 1-inch ring, and quartered to provide a 15-pound sample for the laboratory.   When quicklime is shipped in barrels, at least 3 per cent. of the number of barrels are to be sampled.   They should be taken from various parts of the shipment, dumped, mixed and sampled as above.   All samples to be sent to the laboratory must be immediately transferred to an air-tight container.

To test the sand-carrying capacity of lime, the latter is first slaked to form a thick plastic putty and briquettes are made employing varying proportions of this putty (equivalent to a definite quantity of dry lime) and standard Ottawa sand.   The sand and putty are thoroughly worked to form a plastic mortar and the briquettes are made as described in Arts. **19** to **22**, inclusive, for cement testing.   They are stored in air, not water, and are broken at periods after 3 months.

To find the percentage of waste in quicklime, 5 pounds of lime is placed in a box and slaked with sufficient water to produce the maximum quantity of lime putty.   If too little water is used the lime will burn, if too much it will be drowned.   The putty is allowed to stand for 24 hours and then washed through a 20-mesh sieve by a stream of water having a moderate pressure. No material is to be rubbed through the screens.   Not over 3 per cent. of the weight of the selected quicklime nor 5 per cent. of run-of-kiln quicklime should be retained on the sieve.   The sample of lump lime taken for this test should be crushed to 1 inch and screened over a $\frac{1}{4}$-inch screen and only that portion used which remains on this screen.

61. Percentage of Available Free Calcium Oxide. Lime is much used in the chemical industries and for this purpose it should show a high percentage of free calcium oxide. The following is the usual test made to determine this: Weigh 28 grams of the coarsely ground sample into a liter graduated flask containing about 250 cubic centimeters of recently boiled distilled water. Boil for 10 minutes, close with a cork containing a capillary tube 6 inches long and allow it to cool somewhat. Make up to the mark and mix well. Immediately after mixing draw off 50 cubic centimeters of the milk of lime and titrate at once with normal hydrochloric acid, using phenol phthalein as an indicator. Allow the flask to remain some time to see whether the pink color returns. For the percentage of free calcium oxide multiply the number of cubic centimeters required by 2.

In the case of hydrated lime use a 1.4-gram sample, place it in an Erlenmeyer flask with 250 cubic centimeters of water, and titrate the entire volume after boiling and cooling as described. In the case of quicklime, the larger weight is necessary in order to get a proper average.

62. Hydrated Lime.—Hydrated lime is packed in bags and is sampled just as cement, but the sample should be put in an air-tight container. The fineness of hydrated lime is determined by means of the No. 100 and No. 30 sieves. A good hydrate will not leave a residue of over 5 per cent. on a standard No. 100 sieve and not over .5 per cent. on a standard No. 30 sieve.

To determine soundness, which is due to the thoroughness with which the lime has been hydrated, equal parts of hydrated lime under test and Portland cement which is known to be sound are thoroughly mixed together and gauged with water to a paste. Only sufficient water should be used to make the mixture workable. From this paste a pat similar to those already described in Art. **26** is made, allowed to harden 24 hours in moist air, and subjected to the steam test. The pat must stand the test without popping, checking, cracking, warping, or disintegrating.

ANALYSIS AND TESTS OF PLASTER

63. The constituents usually determined are silica, insoluble iron oxide and alumina, lime magnesia, sulphur trioxide, and combined water. The first seven of these are determined as in Arts. **31** to **38**, inclusive, for cement, the combined water is obtained by placing 1 gram of the sample in a covered crucible, weighing the whole, and heating in an air bath at a temperature from 215° to 230° C. for 1 hour. The crucible is weighed, again heated for 15 minutes, and again weighed, and this treatment is repeated until it ceases to lose weight as shown by two weighings with intervening heating agreeing to within .2 milligram. Report the difference between the first and last weight of the crucible as combined water.

64. Plaster is usually tested for fineness, setting time and tensile strength. The fineness is found by sieving through a No. 100 sieve. The setting time is determined with the Vicat apparatus. The tensile strength is determined by molding into briquettes. The plaster for both the setting-time and tensile-strength tests is mixed with just enough water in a pan to make a mixture fluid enough to pour and not stiff as in cement testing. The plaster is poured into the rings of the Vicat apparatus and also into the briquette molds and is not pressed in as is done in cement testing. Tests made by different laboratories rarely agree and are consequently only of value when made by the same operator, and are hence of use principally for comparing two or more plasters. When called upon to test an unknown plaster, therefore, procure one which is known to give satisfaction in use, and test the two side by side.